Evidence-based eLearning Design: Develop and Trial a Prototype Software Instrument for Evaluating the Quality of eLearning Design Within a Framework of Cognitive Load Theory

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Submitted for Degree of PhD 19 October 2020

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Abstract

A major research direction within higher education in Australia and internationally is the evaluation of learning design quality and the extent to which the design–teaching–learning–evaluation cycle is evidence based. The quest for increased evidence-based learning design, which has been influenced by evidence-based medical research standards, is driven by its link to improved learning outcomes, higher learner engagement levels and lower attrition rates. Cognitive Load Theory (CLT) has risen to prominence over the past three decades as an evidence-based framework for informing instructional design in traditional, blended and multimedia learning environments. CLT approaches learning from the perspective of engaging specific strategies to manage the loads imposed on a limited working memory in order to form and automate long-term memory schemas. CLT operates on the premise that optimal learning conditions may be obtained by aligning pedagogical strategies with the structure and functions of human cognitive architecture and the individual learner's prior knowledge. CLT has contributed a suite of strategies derived from a unified model of human cognitive architecture and validated through randomised controlled trial (RCT) experiments as exerting strengthening effects on learning, thus suiting the CLT framework for use as an evidence-based standard in this study.

Up to this point, a single digital system has not yet been developed for managing, monitoring and evaluating the implementation and impact of CLT strategies at scale. The key contribution of this study is a new prototype software instrument called Cognitive Load Evaluation Management System (CLEMS) that addresses this issue and also provides a model for its implementation. CLEMS is underpinned by a personalised model of teacher–learner interactions defined as mediative–adaptive in nature that includes diagnostic conversations (DCs) for identifying barriers to learning, interventions called Nodes of Expertise (NOEs) for advancing learners to new levels of understanding of complex knowledge, and validation conversations (VCs) for evaluating learner progress. In addition, the heutagogical or self-directed learning capability of learners, including motivation, has been brought to the fore as a significant factor contributing to schema automation.

A qualitative Design-based Research (DBR) methodological approach was used to develop CLEMS, which emerged over three research iterations through the synthesis of literature review findings and empirical data from expert focus groups. Emergent data was continuously triangulated between research iterations and ongoing literature reviews to refine the design and development of CLEMS from a theoretical model to an operational digital prototype.

The conceptual framework of the study has been derived from Critical Realism (CR) which posits an ontological–epistemological view of reality that is stratified and multi-mechanistic, thus aligning with the complex nature of authentic learning environments as well as the multi-faceted model of human cognitive architecture contributed by CLT. The implications of the study have been discussed with reference to stakeholders including teachers, learners and educational institutions.

Recommendations for future research include the ongoing development of CLEMS for the systematic implementation of CLT strategies at scale.

Keywords: andragogy; barriers to learning; cognitive load theory (CLT); Cognitive Load Theory Evaluation Management System (CLEMS); intrinsic; extraneous; germane; cognitive task analysis (CTA); conceptual framework; continuous improvement; Campbell Collaboration; Cochrane Collaboration; critical realism; design-based research (DBR); design–teaching–learning–evaluation cycle; double-loop evaluation framework; evidence-based learning design; extraneous cognitive load; germane cognitive load; heutagogy; human cognitive architecture; instrinsic cognitive load; learning; means–ends analysis vs. schema-based learning; long-term working memory; personalised learning; pedagogy; taxonomy of learning design categories; threshold concepts; synthesis and emergence.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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I acknowledge the support I have received for my research through the provision of an Australian Government Research Training Program Scholarship.

Signature: ………………………………………

Acknowledgements

This thesis was proofread and copyedited for grammatical, typographical and spelling errors by professional accredited editor Mary-Jo O'Rourke AE according to the national university-endorsed 'Guidelines for thesis editing' (Institute of Professional Editors, 2019) and the University of Adelaide editing requirements.

I would like to express my heartfelt thanks to:

My wife and daughter for their incredible patience and support through my seven year PhD journey. I am indebted to them for their love, tolerance and encouragement and especially to my wife for proofreading and copyediting the final version of the thesis.

My lead supervisor Dr Edward Palmer who guided the entire process with insight, continuous encouragement and expert knowledge of software design and development from his own PhD thesis study.

My supervisors Dr Cate Jerram, Dr Philip Uys and Dr Juhani Tuovinen for their limitless encouragement, inspiration and immense patience as they have guided me through researching and writing my PhD. I couldn't have wished for a better supervisory team.

Family, work colleagues and friends including Charles Da Costa, Nukunu Nanedo, Joseph Kamara, Warren Sargent, Bruce Watson, Glen Shearer and others too numerous to mention by name for their interest, support and guidance through the long journey of being a remote part-time student.

Other friends and family members, too numerous to mention individually, who encouraged me on this journey.

My Heavenly Father for enabling me to embark on this journey of learning; and His Son Yeshua, my Saviour and Messiah, who has given me hope in this life and the assurance of an eternal future in His presence.

Key terminology and acronyms used in this thesis

Note: Appendix A contains a comprehensive glossary of terminology, acronyms and definitions.

Term/Acronym	Meaning
Automation	Elements or chunks of knowledge that have been processed in working memory to the point of unconscious execution
AR	Action Research
CF	Conceptual Framework
Campbell Collaboration	Research standards body for humanities
Chunking theory	Cognitive theory of expertise
CI	Continuous improvement
CLT	Cognitive Load Theory
Cochrane Collaboration	Research standards body for medical research
Cognitive load	The mental effort applied by a learner to process elements in working memory
CLEMS	Cognitive Load Evaluation Management System; system developed in this thesis in response to the research question
Cognitive Load Theory Effects	Outcomes related to engaging the functions and interrelationships of working and long-term memory systems
Cognitive Load Theory Strategies	Teaching and learning approaches based on effects identified through randomised controlled trial experiments
CR	Critical Realism; ontological paradigm of this study
CTML	Cognitive Theory of Multimedia Learning
DBR	Design-based Research; methodological approach used in this thesis
DC or DCs (plural)	Diagnostic conversation; teacher–conversation to identify barriers and create targeted learning interventions
DKD	Dynamic Knowledge Database; part of CLEMS
Double-loop learning evaluation	Evaluating learning outcomes as well as the underpinning theories and assumptions of learning design
Element interactivity	Number of elements required to be processed in working memory during learning
Evidence-based teaching and learning	Teaching and learning that is based on a defined standard of research evidence
Expertise Pathway Model	Tool contributed through this study to support teachers in the learning design process
Extraneous cognitive load	Load imposed on working memory that does not relate directly to schema formation and automation
Fluency Plus/Minus 1 Model	Tool contributed through this study to support teachers in the learning design process
Germane cognitive load	Mental effort applied directly to the formation and automation of schemas
Heutagogy	Self-determined learning capability
Information-age (IA)	A learning model that is individualised and adaptive to the needs of learners within a technological framework
IS	Information Systems
Intrinsic cognitive load	Inherent level of complexity in learning content taking learner prior knowledge into account
Knowledge/Heutagogy Quadrant	Tool contributed through this study to support teachers in determining the prior knowledge level of learners
Learning	A persistent or permanent change to long-term memory schemas

Learning design	Term used in this thesis to describe the deliberate process of creating learning interactions that form and automate long-term memory schemas
LTM	Long-Term Memory; knowledge store with unlimited capacity
LTWM	Long-Term Working Memory; construct for bypassing the limitations of working memory
LMS	Learning Management System
Means-ends analysis	A cognitive mechanism that sends learners into a search process to narrow the gap between the known and the end goal when they don't have prior knowledge schemas
NOE or NOEs (plural)	Node of Expertise; a learning episode designed to form and automate schemas in domain-specific knowledge
Principles of Cognitive Load Theory	Description of five underpinning mechanisms of cognition during learning
Schema	A long-term memory structure in which knowledge elements are combined and stored
Sensory Memory	Memory system that holds sensory impressions briefly after the stimulus has discontinued
Synthesis and emergence	Themes underpinning the conceptual framework of the current study
Unified model of human cognitive architecture	Model contributed by Cognitive Load Theory research that explains the functions and interrelationships between working memory and long-term memory during learning
VC or VCs (plural)	Validation Conversation; debriefing conversation between teacher and learner after learner completes a Node of Expertise
WM	Working Memory; conscious memory, limited in processing capacity and duration of retention

Chapter 1 – Introduction

1.1 Origin of this study

This chapter introduces the key issues and challenges that gave rise to this study, as well as the researcher's initial response to issues and challenges concerning design that arose in the workplace. It progresses to discussing the influences that shaped the notion of developing a new software instrument for evaluating and improving the quality of learning design, which later in the study was given the acronym CLEMS (Cognitive Load Evaluation Management System) and is therefore mostly referred to as CLEMS in this thesis. Finally, it outlines the themes and knowledge areas that were identified as having the potential to contribute to the development of CLEMS.

The adoption of Cognitive Load Theory as a theoretical framework for CLEMS was not a foregone conclusion at the start of the study. While preliminary research suggested the potential of CLT for serving this purpose due to its theory-to-practice link, it was through the literature review that this choice was validated. CLT was identified through a progressive filtering process as a viable framework for informing the development of CLEMS. However, the acronym CLEMS has been used for convenience of reference throughout the thesis.

This study was motivated by a set of recurring challenges that emerged from different stakeholder groups in educational institutions during the researcher's role as an instructional designer and teacher.

a. Instructional designers expressed the need for an efficient and effective way to evaluate the quality of existing eLearning courses against an objective standard. This was needed to validate and report on the extent to which developed learning programs were evidence-based.

b. Senior stakeholders, both in institutions new to learning technology and in those that had implemented advanced learning technologies, repeatedly asked basic questions such as:

- What is eLearning?
- What is learning design?
- What is pedagogy?

These questions reflected a need for the provision of professional development to keep non-teaching staff up to date with key ideas and terminology in learning design.

c. Time-poor teachers, lecturers and trainers expressed the need for more personalised learning interventions to support learners in their current studies and future learning aspirations. This was expressed by the need for factors such as evaluating the extent to which teaching and learning practices were evidence-based, real-time feedback on learner progress, as well as systems for providing rapid and appropriate support to learners in terms of their needs, including disability (Australian Department of Education and Training, 2005). In some cases, students had failed courses multiple times and were advised to repeat courses until they passed. This reflected the need for teachers to access more specific diagnostic tools to pinpoint specific barriers to learning so that students who were at risk of floundering in their progress, or dropping out of their studies, were adequately supported.

d. Information Technology (IT) staff reflected the need for insight into pedagogical practices to communicate more effectively with stakeholders. This new level of communication would provide greater clarity in understanding the learning delivery needs of institutions through providing appropriate learning technologies and support. This pointed to the need for efficient feedback mechanisms such as the use of analytics and visualised reports to facilitate the translation of pedagogical needs into technological solutions.

e. Administrators and senior managers needed more effective ways to understand the educational and aspirational needs, as well as learning risk profiles, of students. Besides providing a more personal view of learners, this information could inform policy and budgeting decisions, as well as provide information to inform continuous improvement (CI) of teaching and learning, and ultimately contribute to a better understanding of the causes of student attrition in higher education (Bond, 1999; Briggs, 2013; Cobb, 2001; Kerby, 2015; Lamb & Bain, 2004; Nguyen, 2015; Pitman & Moodie, 2017; Universities Australia, 2017).

f. Students wanted to verify that the programs or courses they were committing to study would:

    1. provide relevant and meaningful learning experiences.
    2. support their personal learning, social learning and aspirational needs through accurate appraisal of knowledge and skills levels, with real-time feedback to support their progress.
    3. enhance their learning capabilities through skill development
    4. enable the successful completion of their studies.
    5. equip them with graduate attributes, professional attitudes and current skills to ensure a successful transition and adaptation to their future workplaces.

Superficially, the above challenges arising from the researcher's practice appeared disconnected and separated by institutional management hierarchies or departments. On reflection, however, they were in fact deeply connected by a common goal. This goal was the quest for systems that provided assurance of the quality of learning design in serving the educational and aspirational needs of each individual learner, as well as of transparency of learners' progress towards higher levels of expertise in their chosen knowledge domains.

The challenges, problems and issues expressed by these stakeholders prompted the researcher to consider the possibility of developing a single software tool for addressing them. While the initial conceptualisation of CLEMS was only formative, some useful characteristics were identified, representing as a convergence of factors that would address the articulated challenges. One of these factors was the notion of an Information Age (IA) model or paradigm of teaching and learning identified in the literature (Aslan, Huh, Lee & Reigeluth, 2011; Francom, 2017; Hancock, 1997; Huang, Huang & Chen, 2006; Reigeluth, 1999; Reigeluth 2009). This model is highly personalised, adaptive to the needs of learners and technologically driven. By adapting and modifying this theoretical model to inform the practical development of CLEMS the following picture emerged:

CLEMS would be need to be rapidly deployable for evaluating the quality of learning design during in situ teaching environments:

- it would need to be based on an objective evidence-based learning design standard;
- it would also need to provide specific, visualised feedback in the form of actionable information required by each stakeholder, preferably in real time e.g. educators who need to design learning interventions
- it would need to be database-driven, with the capability of storing information for quality monitoring and tracking in the long term
- CLEMS would need to have the capability of data mining e.g. analysing accumulated data sets to identify trends and inform the continuous improvement of learning design. Any use of data for analytics would be subject to applicable privacy laws.

Ongoing, informal discussions with colleagues and experts affirmed that an instrument of this nature would be very useful if it could be developed.

However, it was also evident that research would need to be conducted to identify an appropriate evidence-based framework for informing the development of an instrument such as CLEMS. Preliminary searches suggested the potential of CLT to serve as an evidence-based evaluation standard for CLEMS (Mayer, 2005; R. C. Clark, 2010; Sweller, 1988), but further investigation was required into the place of CLT in the status quo of current approaches to learning design (Chapter 2), the research paradigm underpinning CLT (Chapter

3), as well as the historical research foundation of CLT (Chapter 3).

To this point, the problem area of how the quality of eLearning may be evaluated and improved has been defined in general terms. In this study, the terms design–teaching–learning–evaluation cycle, or full cycle of learning, are used to refer to the complete, cyclical process of learning design from a pedagogical perspective, or parts thereof; however, it is acknowledged that some approaches to education only include parts of this process, not necessarily the full cycle.

A research direction for addressing the problems under discussion has been proposed in the form of a technological artefact such as CLEMS that considers the full design–teaching–learning–evaluation cycle.

The next sections of the chapter set the backdrop for this study in greater detail. Emergent themes for addressing the stated challenges are identified and a framework for developing CLEMS is conjectured and discussed.

1.1.1 Roadmap of this chapter

Section 1.1.2 clarifies the terminology used in the thesis. Section 1.1.3 introduces Bloom's concept of evidence-based educational practice and Section 1.1.4 introduces the work of Sweller and other researchers who established CLT, with Section 1.1.5 providing a summary of both Bloom and Sweller's work and the significance of their contributions to evidence-based teaching practice. Section 1.1.6 highlights the problem of accessing evidence-based educational strategies from a single source of truth, and Section 1.1.7 provides additional support for reviewing the current systems with the aim of increasing evidence-based educational practice. Section 1.1.8 provides a statement of the core enquiry of the study. Section 1.2 elaborates on the need for evaluating learning design and its possible economic implications for education in Australia. Section 1.3 outlines the basic premise of the study, that a link exists between the quality of learning design and the quality of learner achievement outcomes. Section 1.4 introduces the necessity for a double-loop evaluation model for evaluating learning design and Section 1.5 highlights the need for a technological framework for implementing this model of evaluation. Section 1.6 introduces the notion of an information-age (IA) educational model of learning design, teaching, learning and evaluation as the basis for a technological framework for managing the proposed dual level evaluation process and Section 1.7 clarifies the research gap addressed in the study. Section 1.8 describes design-based research (DBR), the approach that has been selected as appropriate for the study and Section 1.9 rationalises focus groups with expert educators as participants as an appropriate method of data-gathering.

Section 1.10 describes the scope and delimitations of the research study. Section 1.10.1 defines research boundaries, while Section 1.10.2 outlines the limitation of the study to higher education in Australia. Section 1.11 discusses the significance of the study and Section 1.12 outlines the remainder of the thesis.

Some overlap of meaning exists in the literature between the terms learning design and instructional design as follows: A learning design documents and describes a learning activity in such a way that other teachers can understand it and use it in their own context; typically, a learning design includes explanations about how learning tasks are conducted, as well as the environment, supports, learning conditions and resources facilitated by teachers (Donald, Blake, Girault, Datt & Ramsay, 2009). Instructional design has been referred to as a systematic, reflective process of transposing specific learning principles into pedagogical interventions including teacher–learner interactions, instructional activities, materials, resources – and evaluation. In this regard an instructional designer, or learning designer is similar to an engineer (Mayer, 2005; Merrill, Drake, Lacy & Pratt, 1966; Smith & Tillman, 1999).

Some key differences exist between the terms learning design and instructional design, particularly the differentiation between educator-centric instructional processes (King, 1993) and learner-centric educational processes (Bartle, 2015; Mah, 2018; Voorhees & Bedard-Voorhees, 2017). In this study, learning design is favoured (Kirschner, 2002; Phillips, McNaught & Kennedy, 2012; Sawyer, 2014; Sweller, 1988, 1999, 2006), as it implies a personalised, learner-centric approach to education where the individual learner's cognitive architecture (Anderson, 1983; Sweller, 1988) and prior knowledge form critical components of the learning process (see Learning).

1.1.2 Bloom's contribution to evidence-based educational practice

The notion of evidence-based practice is not new in education. Bloom (1968) built the case for personal tutoring and mastery learning as a foundational, evidence-based principle of effective education (see Appendix B). At the core of this assertion was the principle that "aptitudes are predictive of rate of learning rather than the level (or complexity) of learning that is possible" (Bloom, 1968, p. 4). Bloom (1984) remained an influential voice in advocating for the use of experimental research in education to determine the most appropriate learning interventions for learners. He and his research cohort conducted repeated randomised controlled trial (RCT) experiments which linked combinations of evidence-based teaching practices to the quality of learning outcomes. These experimental findings were published in a landmark article titled: "The 2-Sigma challenge; Seeking an objective, evidence-based standard for achieving similar results at scale than can be achieved through 1-to-1 tutoring" (Bloom, 1984, p. 4).

Bloom's article expressed the need for the establishment of evidence-based practices in teaching; moreover, it identified key outcomes from two formats of instruction:

a. mastery learning, where learners in classes of thirty had high levels of corrective feedback;

this resulted in learning outcomes one standard deviation above the norm; and

b. personal tutoring, where learners worked in groups of two or three; this resulted in learning outcomes two standard deviations above the norm.

Bloom's research strengthened the case for the use of RCTs in educational research as a standard for determining the quality of learning design within an evidence-based framework (Anderson-Loy, 2015). Bloom's argument for evidence-based practice arose from the results of his experiments which demonstrated that the default achievement levels of learners within non evidence-based teaching environments was not an accurate reflection of their achievement capability. In other words, the evidence from Bloom's RCTs validated the argument that learners could transcend norm-referenced categories of achievement and rise above their default limitations through the deliberate and intentional use of specific teaching strategies or interventions. A key factor underpinning Bloom's (1968) argument is that learning environments need to be structured on criterion-referenced principles (Bond, 1996), where the time taken for learners to achieve mastery would vary according to the personal learning needs of individual learners i.e. an adaptive learning model of education.

By setting the bar for the use of evidence-based teaching strategies derived from RCTs, Bloom effectively posited a model of education that could arguably address ever-present issues of learner disengagement and student attrition levels in higher education (Adusei-Asante & Doh, 2016; Australian Association for Researching Education, 2004; Bond, 1999; Chipchase et al., 2017; Kerby, 2015; Macheski, Buhrmann, Lowney & Bush, 2008; Maltby & Mackie, 2009; Nguyen, 2015; Willcoxson, Cotter & Joy, 2011; Woodley & Simpson, 2014). Bloom's advocacy for highly-flexible learning environments in terms of time structures was counter-intuitive to traditional learning formats that were less flexible and strongly constrained in terms of time frames. Recent research supports Bloom's position regarding the efficacy of mastery learning (Hussain & Suleman, 2016; Hymel & Dyck, 1993; McGaghie, Barsuk & Wayne, 2017).

1.1.3 Sweller's contribution to evidence-based educational practice

During the time Bloom's experiments were being conducted, John Sweller was also pursuing an evidence-based research direction through CLT, which was "designed to provide [evidence-based] guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance" (Sweller, 1988; Sweller, van Merriënboer, & Paas, 1998). CLT was developed on the foundation of an information-processing model of cognition (De Groot, 1965; Gobet, 1998, 2016; Miller, 1956; Simon, 1979) and was strongly rooted in cognitive psychology and studies of expertise (Ericsson, 1988; Feltovich, Prietula & Ericsson, 2006). CLT focused on identifying and devising specific strategies for managing the loads imposed on the limited working memory system during learning to facilitate efficacious intellectual performance and to investigate conditions that promote the far transfer of knowledge, a research area with a long history (Thorndike & Woodworth, 1901). This process was underpinned by curating the formation and automation of long-term memory schemas using teaching and learning strategies derived from RCTs (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011). Mayer (2005) exended the application of CLT into multimedia environments through the Cognitive Theory of Multimedia Learning (CTML)(Appendix C).

The view of learning espoused by CLT has been informed by historical research into the structure and functions of cognition during learning, with a particular focus on novice learners. This model was derived from over one hundred years of research that investigated the nature of remembering and forgetting (Ebbinghaus, 1885), as well as the governing entities and mechanisms underpinning these phenomena. These entities included working memory and long-term memory, while the governing mechanisms included the interactions between these entities (Ericsson & Kintsch, 1995) and how the weak and strong learning effects occurred during learning based on the design of learning environments (Kalyuga, 2007).

CLT included research on the limited processing capacity (Miller, 1956) and duration constraints (Cowan, 2010) of working memory, as well as schema formation in long-term memory as a core learning mechanism (Bartlett, 1932). CLT also embraced the base of research into expertise (de Groot, 1965; Simon & Chase, 1973), in which the automation of domain-specific knowledge consisting of high element interactivity learning content constitutes the basis of the intellectual performance of experts (Sweller, 1988, 1999). Based on historical research related to cognition during learning, CLT research pursued a direction that focused on the design of learning interventions for intentionally managing the loads imposed on a limited working memory as schemas were formed and automated, as well as the cognitive mechanisms within and between working- and long-term memory that govern the execution of problem solving strategies (Chase and Simon, 1973a; de Groot, 1956; Sweller, 1988). A significant factor regarding Sweller's early research into the structure and functions of human cognitive architecture during learning was the computational modelling of working memory processes using a production system language called PRISM. This resulted in validating the assertion that "means–ends analysis imposes a greater cognitive load than a nonspecific goal procedure" (Sweller, 1988, p. 264). By using PRISM to model the mental processes experienced by novices, Sweller's experiments validated the need for applying specific strategies for managing cognitive loads during learning to gain the strongest learning effects.

Cognitive psychology, through the contribution of Sweller's unified model (de Jong, 2010) of human cognitive architecture (Sweller, Ayres & Kalyuga, 2011, p. 242; Tindall-Ford, Agostinho & Sweller, 2019, pp. 232–238), therefore provided a credible link between theory and practice in education. The alliance between cognitive psychology, with its findings related to the role of cognitive architecture during learning, and education, contributed a robust model of human cognitive architecture for understanding learning effects, as well as designing and evaluating the quality of teaching practices using findings from RCT experiments. It was this body of research that became the raison d'être of CLT, since it presented a cogent and unified model of learning, informed by RCTs, that could both explain and predict learning effects (see Compound effects).

This model and its implications for learning design are further investigated in Chapter 4 of the literature review. It contains a survey of approaches to the design–teaching–learning–evaluation cycle of education that validates the selection of CLT as the theoretical framework of this study.

1.1.4 A summary of contributions by Bloom and Sweller

While Bloom conducted experiments that contributed towards the establishment of evidence-based strategies as an educational standard, Sweller extended the boundaries of this research to a cognitive level. He included and validated the historical research bases into cognition as being significant to learning. Moreover, he provided a unified model of cognition that accounted for not only the functions of individual components of human memory systems, but explained their interactions in terms of these functions. The result was a predictive model from which it could be hypothesised and demonstrated why certain pedagogies were effective or ineffective for different learners along the novice-expert continuum.

Since Sweller's early experiments in the 1980s, a growing cohort of researchers has established principles and effects for strengthening learning based on this model, suggesting that CLT represents a base of knowledge suitable for developing an evidence-based evaluation standard.

1.1.5 The problem of accessing key research findings from a single source of truth

The collated findings of CLT and its application to multimedia learning environments through the cognitive theory of multimedia (CTML) (Mayer, 2005) and the seminal publication, Cognitive Load Theory (Sweller, Ayres & Kalyuga, 2011) represent critical contributions to the field of evidence-based practice. However, CLT findings have not been systematised and collated into a single source of truth within a technological framework that is reasonably accessible for implementation and monitoring in learning environments. Time-poor educators wishing to implement CLT systematically in their teaching environments could be vulnerable to the split-attention effect due to CLT findings being distributed across a broad array of written sources. This could result in cognitive overload and less than optimal application of CLT findings due to the sheer volume of findings from CLT requiring consideration and systematic application.

This identified a gap for the development of a software instrument that could make CLT findings and their application accessible from a single, collated source. The nature of this gap is further explored in Section 1.9.

1.1.6 Further investigations into evidence-based educational practices

Investigating the emerging needs for evidence-based practice in education brought a range of additional research directions to the fore. For example, Masters (2018, p. 3) observed that assessing the quality of educational research occupies an increasingly important role in determining the funding to support research and the work conducted by public universities, stating that:

> Highly-effective teaching requires evidence-informed decision making at crucial points in the teaching process. First, effective teachers use quality evidence to establish the points individual learners have reached in their learning. This enables teachers to identify starting points for further teaching and learning and to ensure that each student is given learning opportunities at

an appropriate level of challenge.

Clark (2010) also contributed to this discussion by providing a useful perspective on the validity of the quest for evidence-based practices in education. Included in this perspective are considerations such as: the importance of determining effect sizes of different teaching practices; limits and constraints concerning evidence-based practices, such as budgets and time; evidence-based practices as a foil for “fads” and unsubstantiated claims regarding the effectiveness of certain teaching strategies (R.C. Clark, 2010, pp. 7–23); and the advantages of meta-analyses of educational experiments. These considerations, which also echo the views of leaders in the broader educational community, contribute key points to the argument for greater evidence-based practices presented in this thesis (Anderson, Johnson & Milligan, 2000; Durham University, 2011; Masters, 2010).

1.1.7 The core enquiry of this study

The core enquiry of this study is therefore motivated by the need to address the challenge that, as educators, “We never really know how effective we are in our teaching… we really have no idea about our students’ understandings” (Phillips, 2002, p. 1). While this view may be extreme, it does bring into focus the need to evaluate learning at a more specific level i.e. at the level of understanding of the cognitive mechanisms that underpin learning processes and outcomes.

Other researchers also support the view that while it appears to be a straightforward process to evaluate answers to test or examination questions and obtain surveys about student experiences of lecturers and courses, a significant challenge is presented if the goal is to evaluate levels of the student’s actual understanding (Entwhistle, 2009; Sweller, 1988, 1999, 2006). The problem of attempting to obtain a true picture of where learners are in their understanding within specific knowledge domains is made even more challenging by the lack of homogeneity of learners in terms of background knowledge and preparedness for learning in contemporary learning environments. This is because a learner's understanding of particular concepts may be incorrect, resulting in learning barriers and poor achievement. However, where thinking processes that learners are engaging can be made visible, they can be modified or rectified by someone with higher levels of knowledge or expertise: a more knowledgeable other, of MKO (Vygotsky, 1978). The themes of visible thinking (Bergeron, 2017; Collins, Brown & Hollun, 1991), visible learning (Hattie, 2009, 2012) and understanding the processes within the black box of cognition (Hamlyn, 1990; Grant, 1992) represents the quest to "exteriorize cognitive operations" (Pask, 1975, p. 1) in order to understand and repair, validate or improve the mental models of learners (see Appendix P) within an evidence-based framework.

1.2 The need for evaluating the quality of learning design

To this point, the theme of evaluating the quality of learning design has been developed. Ehlers and Pawlowski (2006, pp. 1–2) support this view as follows:

- "There is no doubt that quality is the most decisive factor determining the future of eLearning"
- "Quality in eLearning brings together the field of education, technology and economy in comprehensive concepts in order to contribute to societal development"
- "The task to develop or provide a high-quality educational experience is, however, especially in the field of eLearning an extremely difficult challenge. First, it is necessary to find a valid perspective and definition of quality ... a learner's view may differ considerably from the view of a teacher, developer or the government".

While the need to evaluate the quality of learning design is strongly reflected in the literature, it is evident that efficient systems for synthesising data for informing learning design are also needed, both at a classroom teaching and institutional level. In other words, strategies that have been established through high-quality research require systemisation for their consistent implementation and management at scale for the benefit of every learner.

While the broader economic impact of evidence-based learning design at school level on Australian society is beyond the scope of this study, it is an area that invites further research. For example, the Centre for International Research on Education Systems (CIRES) and the Mitchell Institute of Victoria University published a report titled "Counting the costs of lost opportunity in Australian education" (Lamb & Huo, 2017). This report models the cost to the Australian economy of excessively high Year 12 non-completion rates (up to 25% per year) as over AUD50 billion over the lifetime of a cohort of 45 000 learners for a single year of non-completion (Lamb & Huo, 2017, p. 4).

Bloom's (1984) prediction that evidence-based learning design could result in a 90% success rate at school suggests that adopting this approach could contribute to closing the gap between non-completion and completion rates, exert a positive financial impact on the Australian economy and arguably a positive impact on Australia's international educational rankings. By extension of this argument, it is also projected that higher secondary school completion rates could also impact the number of learners choosing to engage in post-secondary education.

1.3 The link between learning design and learning outcomes

The basic premise of this study is that a link exists between the quality of learning design and the quality of learner achievement outcomes (Ambrose, Bridges, DiPietro, Lovett & Norman, 2010; Bloom, 1984; Sweller, 1988, 1999; Sweller, Ayres & Kalyuga, 2011).

One of the key factors in learning design is the level to which learning is personalised to the needs of the individual learner, as opposed to learning that is based on a one-size-fits-all model (Bartle, 2015; Bray & McClaskey, 2015; Department of Education and Training, 2005; Huh & Reigeluth, 2017; Keppell, 2014; McLoughlin & Lee, 2010; Prain et al., 2013). Following on from this premise, this study assumes the principle that the greater the understanding and control that educators have over the quality of techniques and strategies used in learning design, the higher will be the quality of learner achievement outcomes. The more specific the tools that teachers have at their disposal to diagnose the specific barriers to learning encountered by learners, the greater the probability of aligning learning with the needs of learners for successful learning outcomes.

The link between the quality of learning design and learning outcomes (Bloom 1968, 1984; Sweller, 1988; Sweller, Ayres & Kalyuga, 2011) places a high value on identifying and incorporating evidence-based principles of learning design into learning programs and courses. It also places a value on identifying appropriate methods for achieving this, whether using technology or other means. This thesis therefore contributes to the discourse regarding the impact of the quality of learning design on learning outcomes and by implication on society. Siemens and Matheos (2010, para. 3) observe that

> universities today face what may be their greatest challenge as they face globalization, expansion, and economic uncertainty, overlaid by emerging technologies that enable the technologically savvy student body to interact in new ways with content and with each other. This confluence of factors requires the academy to rethink and restructure, both what and how they teach and research, and how they intersect with society.

1.4 The necessity of a dual level or double-loop model of learning evaluation

The notion of a dual level or double-loop (Argyris, 1983, 2002, 2005) evaluation model has been previously introduced as part of the framework for this study. The loop metaphor of the "double-loop" model posits continuous improvement (CI) loops or cycles as part of an evidence-based evaluation model. When this model is adapted to the evaluation of learning environments, learning interventions may be evaluated at two levels; the first level is the achievement outcomes of learners, and the second level is a critique of the design decisions that resulted in the learning interventions. This model articulates a rational basis for a unified system that evaluates learning environments at two levels.

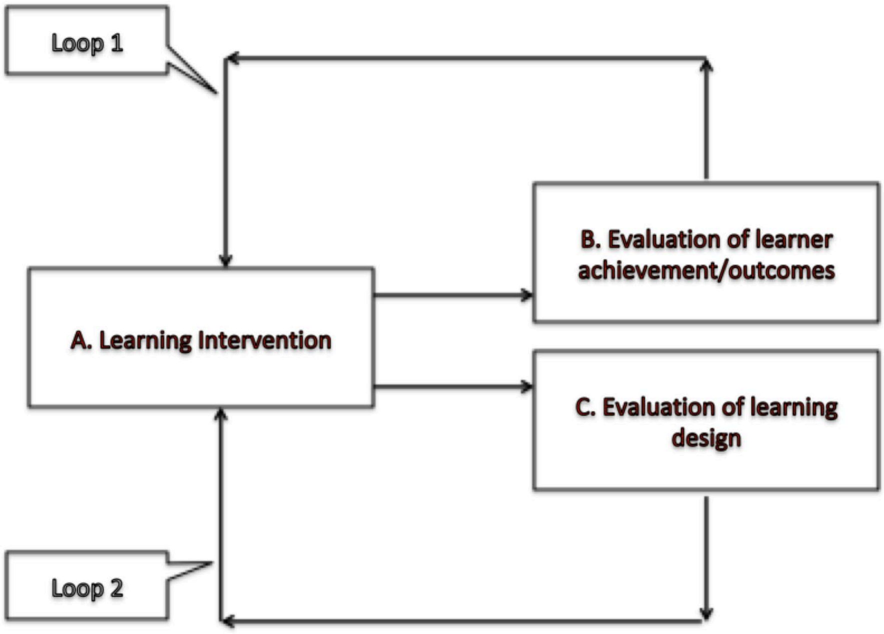

Figure 1.1 Simplified model of the double-loop evaluation system informing this study

Notes: This model has been adapted from the model posited by Argyris (1983, 2002, 2005). A illustrates a learning intervention influenced by two key processes (B and C); B evaluates the achievement outcomes of the intervention and C evaluates the underpinning principles of learning design and "requires re-examination and change of the governing values" (Argyris, 1983, p. 116). The arrows indicate that the double-loop process is continuous, representing a Continuous Improvement (CI) framework of both achievement outcomes and learning design.

This model (Figure 1.1) gives rise to key questions regarding the most effective strategies for advancing learners towards higher levels of expertise:

- What teaching and learning strategies are appropriate within the educational context? (i.e. what is the rational basis of their selection?)

- For which students would the selected strategies be effective? (i.e. on what basis is the readiness of learners for certain interventions determined?)
- Under what conditions should interventions be implemented? (i.e. what learning conditions or environments would support learning?)
- Why these strategies and not others? (i.e. what is the underpinning theoretical model on which these choices are made?)

With the double-loop evaluation model, learner achievement is therefore treated as a different – but interconnected – process from the evaluation of learning design. The first loop relates to outcomes achieved by the learner, as is practised in traditional teaching models (Watson & Reigeluth, 2008). The second loop relates to the underpinning pedagogical method or design used to achieve these goals. In this model, both loops operate simultaneously and effective learning is driven from the perspective of its underpinning design. Stated differently, the second loop in the double-loop model examines, evaluates, critiques, questions and modifies the design of learning interventions against a standards framework in order to align them with increasingly evidence-based practices.

It will emerge through this research that CLT presents a model for the second level of the dual level evaluation model due to its contribution of evidence-based effects and strategies that have been derived from a unified theoretical model of human cognitive architecture (Newell, 1990; Sweller, 1988; Sweller, Ayres & Kalyuga, 2011).

To this point, key themes have been identified as a starting point for addressing the problem of improving the quality of learning design; evidence-based practice, RCTs, dual level evaluation of learning, CI, as well as systems and technologies. The following section further discusses the role of the technology as one of these key drivers in achieving the goal of an evidence-based, dual level evaluation system.

1.5 Cognitive research within a technological framework

The process of developing a prototype CLEMS as the practical culmination of this study has been simplified by access to cloud-based, database-driven applications at relatively low cost. This has made it possible to experiment with advanced functions of data management capability in an unprecedented way (Reigeluth,1999; Wang & Hannafin, 2005). In other words, using software, static models or theories of instructional design may be dynamically formatted, implemented and tested as active models within a software framework.

The need for a technological framework to underpin learning design evaluation does not imply that the use of technology per se results in improved learning design. In this study, technology is engaged to implement principles that have been theoretically and experimentally validated, therefore placing technology in the service of pedagogy. For example, the previously referenced expertise reversal effect (Kalyuga, 2007; Sweller, Ayres, Kalyuga & Chandler, 2003), one of the empirically validated effects arising from CLT, illustrates this point; the expertise reversal effect "states that techniques that are highly effective with inexperienced learners can lose their effectiveness and even have negative consequences when used with more experienced learners". This effect implies the need for the continual, dynamic adjustment of learning interventions to the needs of learners; a requirement that can be fulfilled through the aid of digital technologically-enabled learning environments (DTELEs) (Kalyuga, 2007, 2009a, 2009b; Kalyuga, Rikers & Paas, 2012; Sweller, Ayres & Kalyuga, 2003).

The increased availability and accessibility of technological capability has positive implications for learning design evaluation and its implementation at scale. A consequence of the rising demand for individualised and personalised learning is that large volumes of data are generated that require management and interpretation.

This level of data management and administration would not be possible to achieve through manual processes. However, technology can support educators in managing and interpreting this data through learning analytics and other forms of graphical data reports. Learning technologies with dashboards that provide graphical reports therefore support Bloom's (1984) challenge to deliver the same quality of education as individual tutoring at scale, for example by providing detailed views of learner progress in real time.

Despite the advances of technology to support personalised learning, the view persists that personalised learning for every learner is not possible (Masters, 2018), suggesting that more research is required to understand how personalisation of learning may be implemented, monitored and managed (Bartle, 2015) within digital technologically enabled learning environments.

1.6 The notion of an information-age (IA) model of teaching, learning and evaluation

As previously mentioned, technology has been identified as a key component of CLEMS, which has been envisioned to evaluate and monitor the quality of learning design at scale. This aligns with the general drive to increase the use of technology in higher education, which has potential to facilitate systematised, evidence-based, personalised approaches to teaching, learning and evaluation (Hancock, 1997; Mah, 2018; Reigeluth, 1999). An IA model of learning contrasts with a traditional, one-size fits all, or industrial-age model of learning delivery (Reigeluth, Beatty & Myers, 2017; Reigeluth & Carr-Chellman, 2009; Reigeluth et al., 2008). The IA construct suggests a learner-centric, personalised and adaptive approach to the design–teaching–learning–evaluation cycle.

Reigeluth (1994, p. 3) observed:

> Two things educators know for certain are that different children learn at different rates and different children have different learning needs, even from their first day at school. Yet our industrial-age system presents a fixed amount of content to a group of students in a fixed amount of time, so it is like a race in which we see who receives the As and who flunks out.

Our current system is not designed for learning; it is designed for selection.

IA learning aligns with the notions of equipping learners for twenty-first century (or digital age) skills, or establishing a model of education referred to as the New Learning Paradigm (Kivunja, 2015; Reigeluth, 2012).

The IA construct therefore informs the purpose and functions of CLEMS, which could not only meet the individual needs of learners, but facilitate reflection, modification, monitoring, tracking and reporting of learning interventions within an evidence-based framework in real time. A key functionality within this envisioned model of CLEMS is to include a recommender function (Lu, 2004) that actively responds to analyses of learning environments and individual learners by suggesting evidence-based strategies for strengthening learning. These strategies would be drawn from an internal database that may be populated on an ongoing basis from research findings.

The notion of a recommender function within CLEMS highlights the flexibility of the IA model as a unified system. The IA model therefore serves as a useful framework for designing CLEMS to include the capability of providing immediate, visualised, analytic feedback on learning outcomes as well as the relative effectiveness of the instructional strategy used to achieve the outcomes.

Emergent characteristics of an instrument that used key characteristics of an IA model may be based on the following guidelines:

- contributing to a personalised learning delivery system that takes both learner achievement and learning capability into account in a dual level model (Bartle, 2015; Bray & McClaskey, 2015; Bloom, 1984; Department of Education and Training, 2005; Kalyuga, 2007; Keppell, 2014; McLoughlin & Lee, 2010).
- the systemisation of the design–teaching–learning–evaluation process with the inclusion of digital data storage capabilities for managing, monitoring and reporting on data related

to learners and learning (Reigeluth, 1999; Wang and Hannafin, 2005).

- the inclusion of an evaluation standard derived from evidence-based practice (Bloom, 1984; Sweller, 1999) with feedback reports to different stakeholders using analytic reporting capabilities (Fink, 2003; Larussen & White, 2014; Reigeluth, 1999).
- provision of actionable feedback to educators to inform the development of appropriately personalised interventions for learners as well as evaluating both learner progress and the effectiveness of learning interventions (Argyris, 1983, 2002).
- Facilitation of the continuous improvement of learning design (O'Reilly, Healy, Murphy & O'Dubhghaill, 2017; Sweller, 1988, 1999) using an in-built functionality that recommends specific strategies for strengthening learning design.

These guidelines summarise the key challenge of this study, which is to represent these features and functions arising from the theoretical construct of the IA model within a technological framework, viz. CLEMS; this identifies the research gap that the current study is addressing.

1.7 Identification and clarification of the research gap

Since no similar system for implementing CLT principles and effects has yet been developed, CLEMS is proposed to address the gap for an improved method of implementing, managing and monitoring evidence-based practices in CI cycles. Key themes that govern the study include:

1. Emergence, which is the continual interaction of mechanisms and themes in order to refine propositions and models; for example, the combination of CLT and the information-age (IA) technological framework into a new evaluation instrument, or the convergence of functions such as dual level learning evaluation and CI into a new evaluation model: CLEMS.

2. The notion of an IA framework that accommodates personalisation of learning and adaptive interventions and other needs of contemporary learners; this framework has been adopted as a flexible place-holder for developing CLEMS.
3. The double-loop construct (Argyris, 1983, 2002, 2005) which expresses the simultaneous evaluation of two factors; in this study, the two areas undergoing simultaneous evaluation are learner achievement outcomes and learning design interventions.
4. Actionable knowledge (Argyris, 1996) which is knowledge that is expressed in a form that enables implementation within in situ learning environments. This theme aligns with the goal of this study, which is to place CLEMS into the hands of educators to support the analysis of learners and learning environments, with the aim of designing informed interventions that advance learners to higher levels of domain expertise.
5. Visible learning (Hattie, 2003; Hill, 2006; Ritchhart & Perkins, 2008), which seeks to make unobservable cognitive processes more visible to teachers e.g. where learning experiences might be causing cognitive overload, or where the mental representations that learners are forming to solve problems are erroneous or inadequately formed. The notion of visible learning also implies a high level of transparency regarding teaching processes; this is in order to identify learning interventions that exert a positive, neutral or negative impact on learning outcomes; this level of visibility fosters both reflective practice and supports a common language of communication between educational practitioners e.g. for some unfamiliar concepts related to cognitive processes, such as cognitive load, working memory, long-term memory, schemas, automation, and long-term working memory (LTWM).

1.8 Design-based research (DBR) as a methodological approach

Design-based research (DBR), also called Education Design Research (EDR)(McKenney & Reeves, 2013) and design research (Reeves, Herrington & Oliver, 2005) was selected as an approach for conducting this study after considering the characteristics of numerous research paradigms. DBR, as noted by Bereiter (2002, p. 321):

> is not defined by its methods but by the goals of those who pursue it. Design research is constituted within communities of practice that have certain characteristics of innovativeness, responsiveness to evidence, connectivity to basic science, and dedication to continual improvement.

The Design-Based Research Collective (2003, p. 1) clarifies the characteristics of design-based research in three key areas:

1. Its specific purpose of addressing educational problems
2. Its cyclical and iterative processes for developing artefacts that address a specific problem
3. Blending empirical educational research with the theory-driven design of learning environments.

Within these definitions, DBR therefore aligns with the experimental, goal-driven and iterative characteristics of this research study through its use of expert participant focus groups, micro-phases of research through an iterative process, focus groups consisting of diverse participants, and a design that is flexible and adaptive to facilitate the refinement and improvement of the research design as well as providing a deeper understanding of the research problem being addressed in the study (Kennedy-Clark, 2015).

1.9 Expert research participants

The specific method used to gather empirical data within the DBR approach was using focus groups (Morgan, 1988) with expert educators as participants. Focus groups are an established method within Design-based research. Tremblay, Hevner, Berndt and Chatterjee (2010) exposit the functions of exploratory focus groups (EFGs) in the design cycle of artefacts, by stating that EFGs evaluate the design of an artefact to critique and suggest improvements to it. In addition, EFGs may comprise of several refining cycles of research until the artefact is released for trialling. For these reason EFGs present a suitable research method for this study.

1.10 Scope and limitations of this research

1.10.1 Research boundaries defined

This research concerns the development of CLEMS from a proposed theoretical model to the point of trial as a useable prototype. As the primary focus of the study is on the design process, the research limits the development of CLEMS to a prototype stage for evaluation purposes only, and not for use in a teaching environment. The field-testing of CLEMS within an institution has been suggested as a future research direction.

The second part of the research question, regarding the usefulness of CLEMS, is addressed progressively through the informed opinion of expert educators in three focus groups of the study. The question, “How might CLEMS be useful to educational practitioners and other stakeholders?” was intended to elicit expert opinions regarding applications of CLEMS as well as its future research directions beyond the current study.

The purpose of limiting the scope of development of CLEMS is since it is not intended to be a panacea for all problems related to learning design evaluation, nor does it invalidate any other theoretical paradigms or evaluation processes. The research is framed as an exploratory, initial contribution to evaluation research based on CLT research findings that builds on and extends existing research endeavours to evaluate the quality of learning design. The study aims to achieve this goal through transposing CLT findings into the full cycle of four key pedagogical stages (design–teaching–learning–evaluation) within a technological framework.

1.10.2 Limited research context – higher education in Australia

The research study was conducted within the context of Australian higher education, but has drawn on relevant literature from the international research community. Using international research identifies the challenges to learning design evaluation within a broader context and strengthens the argument for the use of CLEMS within contexts beyond Australia.

The project was initiated by seeking answers to challenges that were recognised within the instructional design community of practice. However, these identified challenges were not intended to be comprehensive, but to represent a cross-section of issues related to the area of learning design evaluation. These may be extended and refined as the basis for future research.

1.11 Significance of the study

The significance of the study is that it extends CLT into a new research direction; specifically, the incorporation of research findings into an IA software architecture for educators to use as a standard for evaluating the quality of learning design. In addition, the use of this architecture suggests additional functions to support learning processes that include four key stages as parts of a systematic and unified process:

a. learning design

b. teaching

c. learning

d. evaluation.

In this study, these four stages are referred to as the design–teaching–learning–evaluation cycle, or full cycle of education.

In summary, this chapter provided a general background to the problem of evaluating the quality of learning design using CLT, which was identified as a potential framework for this purpose, subject to further validation through the literature review.

EFGs were identified as a suitable investigatory method for extending CLT into this new direction. The limitations of the study were outlined, including time and budgetary constraints in developing CLEMS to prototype level, as well as the limitation of the empirical research process to three iterations (Valdosta State University, 2018).

The focal point of this study has been stated as the design of a useable and useful software instrument, viz. CLEMS for evaluating and improving learning design. The study will demonstrate how CLT emerged as a viable framework on which to develop CLEMS due to two key factors:

1. its use of randomised controlled trial (RCT) experiments to derive and validate learning strategies
2. building upon the historical findings of cognitive research to provide a unified model of human cognitive architecture for understanding the structure and functions of working memory and long-term memory during learning.

The goal of translating a theoretical model into a working software prototype presented several challenges e.g. the selection of:

a. the methodological approach by which CLEMS could be designed

b. determining a suitable technological architecture for a CLEMS prototype

c. the useability of the software functions of CLEMS

d. factors for consideration in the usefulness of CLEMS in the educational community.

Encapsulating all the issues raised in this chapter, the main research question of this study is therefore:

> How can the research arising from cognitive load theory inform the development of a prototype software instrument for evaluating and improving the quality of eLearning design that is useful to educational practitioners and other stakeholders?

1.12 Organisation of the thesis

The thesis is organised as follows:

Chapter 1 – Introduction

Introduction and background to the problem addressed in the thesis, theoretical and conceptual frameworks and articulation of the research question.

Chapter 2 – Literature Review (Part A)

Broadly reviewing approaches to education since 1885; the use of key word search criteria, as well as inclusion and exclusion criteria for conducting the review; classifying identified approaches to learning within a taxonomy of 19 categories; identification of CLT as a suitable framework for developing a learning design evaluation standard based on two selection criteria; its use of a model of human cognitive architecture and its derivation of teaching and learning strategies derived from RCTs.

Chapter 3 – Literature Review (Part B)

Narrowing the review funnel by identifying four major educational paradigms and their underpinning philosophies: behaviourism, cognitivism, constructivism and connectivism; the rationale for selecting cognitivism as suitable paradigm for an evaluation instrument. Chapter

4 – Literature Review (Part C)

Focusing on CLT through its historical position withing cognitive research; elucidating the background to CLT as a factor for strengthening its position in learning design evaluation; investigation and review of key cognitive research, as well as researchers who contributed to or influenced the formation of CLT.

Chapter 5 – Overview of Cognitive Load Theory

A deeper and more detailed overview of CLT; the unified model of human cognitive architecture that it posits; the principles on which it is based and the effects and strategies arising from CLT research through RCTs.

Chapter 6 – Conceptual Framework of the Study

The conceptual framework of the study including themes of emergence and synthesis; the ontological perspective of critical realism and its rationale for use in this study; the methodological approach of DBR and the methods by which the theoretical model was translated to a useable prototype evaluation instrument; synthesis of the functions and characteristics of CLEMS into a unified theoretical model for developing into a useable prototype.

Chapter 7 – Methodology and Methods

A rationale for DBR as the selected methodological approach for conducting the study; adoption of the Reeves model of design-based research for conducting the research iterations of the study; methods of data collection including focus groups, literature review and data triangulation; methods of data validation, coding and analysis of emergent data.

Chapter 8 – Research Iteration 1 and Focus Group 1

Description of Research Iteration 1, including literature review and focus group 1; design of data-gathering instruments; coding key for data analysis; summary of responses, discussion and conclusion of research iteration 1; preparation for focus group 2.

Chapter 9 – Research Iteration 2 and Focus Group 2

Description of Research Iteration 2, including literature review and focus group 2; design of data-gathering instruments; coding key for data analysis; summary of responses, discussion and conclusion of research iteration 2; validation of data through triangulation between focus groups 1 and 2, as well as between focus groups and ongoing literature review; preparation for focus group 3.

Chapter 10 – Research Iteration 3 and Focus Group 3

Description of Research Iteration 3, including literature review and focus group 3; design of data-gathering instruments; coding key for data analysis; summary of responses, discussion and conclusion of research iteration 3; validation of data through triangulation between focus groups 1, 2 and 3, as well as between focus groups and ongoing literature review.

Chapter 11 – Discussion, Conclusions and Recommendations

Summary of findings from research iterations 1–3 and focus groups 1–3; review of the outcome in terms of the main research question; implications of the study for stakeholder groups; recommendations for further research; closure.

Appendices

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Table 1.1 Overview of the thesis structure in terms of addressing the research question, which has been divided into three sections (see Section 6.1.1)

<table>
<tr><td colspan="4">Research Question:

A. How can the research arising from Cognitive Load Theory
B. be used to inform the development of a learning design evaluation instrument
C. that is useful to educational practitioners?</td></tr>
<tr><th>Part of research question addressed</th><th>Key areas of investigation</th><th colspan="2">Chapters</th></tr>
<tr><td>Origin of the study and statement of the research problem</td><td>Development and statement of the research question</td><td>Chapter 1</td><td>The need for evaluating the quality of learning design;
the concept of a Cognitive Load Evaluation Management System (CLEMS)</td></tr>
<tr><td rowspan="3">Part A of the research question</td><td rowspan="3">Investigating the background to the research problem in 3 key areas</td><td>Chapter 2</td><td>Approaches to learning design</td></tr>
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<tr><td>Chapter 11</td><td>Conclusions and recommendations</td></tr>
</table>

Chapter 2 – Literature Review: Part A

Determining Levels of Quality in Learning Design

2.1 Introduction

This chapter is the first of three chapters (Chapters 2–4) of the literature review providing the theoretical background to the study, which is situated within the discipline of learning design. It discusses the notion of levels of quality of educational research, which is investigated as the basis for selecting a useful evaluation standard for this study. In addition, approaches to the design–teaching–learning–evaluation cycle have been identified and classified into 19 taxonomical categories, with the goal of supporting the quest for a useable learning design quality standard for this study.

Chapter 3 builds on this survey by investigating the four key educational paradigms that emerged during the 20th century; it has a particular focus on cognitive research as a paradigm for informing evidence-based practice in education; and Chapter 4 investigates the historical roots of the cognitive research that contributed to the understanding of the underpinning mechanisms of learning with regard to working- and long-term memory systems.

While no gold standard (Sullivan, 2011) yet exists for validating learning design, the next section posits a taxonomy for organising approaches to learning that draws on the Cochrane Collaboration, the model used to evaluate quality levels of medical research (Cochrane Collaboration, 2019; Evans & Benefield, 2013; Ryan, Hill, Prictor & McKenzie, 2013) as well as its sister model for determining research quality levels in the humanities, the Campbell Collaboration (Campbell Collaboration, 2019). These two standards provide insight into the different levels of quality of medical research and humanities research, thereby providing guidelines for identifying research that may serve as an evidence-based standard in education and specifically in learning design. One of the highest levels of quality posited by these standards arises from the findings of Randomised Controlled Trials (RCTs) (Morrison, 2001). While RCTs have been flagged as posing a risk in terms of relevance (Cronbach, 1982), they nevertheless represent a valid standard if any perceived risks are mitigated. For example, the evidence-based learning interventions proposed by Bloom (1984) require consideration of the needs of individual learners and are not intended to be applied formulaically or mechanistically within learning environments. The recent re-emergence of RCTs in educational research also strengthens the argument for using RCTs to derive a quality standard for evaluating learning design (Bridges, 2009; Collins, 2017; Connolly, Biggart, Miller, O'Hare & Thurston, 2017; Hempenstall, 2006; Styles, 2018; Sweller, Ayres & Kalyuga, 2011).

One of the key reasons for using a cautious and judicious application of strategies arising from RCTs is the critical impact of the learner's prior knowledge on subsequent learning (Sweller, 1988). A strategy that works effectively for novices might have a neutral or hindering effect on learners with higher levels of prior knowledge, a finding from CLT that has been termed the expertise reversal effect (Kalyuga, 2007; Kalyuga, Ayres, Sweller & Chandler, 2003; Kalyuga, Rikers & Paas, 2012). This implies that the use of a standard such as RCTs for evaluating the quality of learning design therefore has a caveat; while learning is too complex to apply simplistic or formulaic rules with simple cause-and-effect expectations, the educational strategies arising from RCTs should be applied with consideration to other factors that exist in learning environments.

A dual level evaluation model is suggested to facilitate this process; every intervention intended to strengthen learning outcomes requires an additional level of evaluation to determine the actual level of its strengthening or weakening effect. The need for this dual level process affirms the key role of professional educational practitioners for evaluating the relative quality of evidence and devising appropriate intervention strategies for

learners i.e. by taking the prior knowledge of learners as well as additional factors regarding the learning environment and learner characteristics into consideration.
Effects and strategies arising from CLT have been derived from RCTs (Tindall-Ford, Agostinho & Sweller, 2019, p. 238), which are designed to be implemented with the dynamic adjustment of learning interventions to the needs of individual learners due to the expertise reversal effect (Kalyuga, 2007; 2009a, 2009b). However, effects and strategies arising from CLT, whether the full set or sub-sets, have not yet been collated into a format that enables their systematic implementation and monitoring within a digital technological framework – a key goal of this study.

2.1.1 Roadmap of the chapter

Section 2.1 introduces the chapter in which a standard for evaluating the quality of learning design is investigated for use in this study.
Section 2.2 provides the specific criteria for evidence-based practice in education that are useful for informing this study, while Section 2.3 introduces the survey of approaches to teaching, learning and evaluation in the quest for approaches that fulfill the selection criteria. Section 2.3.1 describes the nature of the review as a standard review for the purposes of this study, with characteristics of a scoping review in which key search criteria are stated and identified approaches are organised into a taxonomical format of 19 categories. Section 2.4 defines the review further through inclusion and exclusion criteria, search protocols and method of coding the findings of the review.
Section 2.5 highlights the theme of learning design in ancient and historical texts to note their existence, but also their exclusion from the review due to its focus on research since the late 19th century. Section 2.6 contains 19 sub-sections that define the 19 categories into which the approaches identified in the review have been organised, with a clarifying explanation of each

category and its implications for the study, while the final sub-section (2.6.16) summarises and discusses the taxonomical categories and their significance for the study.

Sections 2.7 and 2.8 provide an overview of the key ideas emerging from the study, in which the theories category occupies a position of distinction; within this category, CLT is identified as a framework that is underpinned by a model of cognition, with its experimental findings arising through RCTs.

Section 2.9 identifies the key role of technology in contemporary approaches to teaching, learning and evaluation, with a specific focus on the information-age model (IA) that encapsulates characteristics of personalised learning through digital technologically enabled learning environments (DTELEs) while Section 2.10 clarifies the rationale for the adoption of CLT as an evidence-based standard for evaluating education research and approaches to the design–teaching–learning–evaluation cycle.

Section 2.11 concludes the chapter with a summary and introduces Chapter 3, which establishes the broader context of the research by providing an overview of four key educational paradigms that emerged during the 20th century.

2.1.2 Evaluation of the quality of learning design

In this study learning design is defined as the intentional selection of teaching strategies and environments for achieving defined learning outcomes while considering the theoretical rationale or evidence-based justification underpinning these choices (Argyris, 1983, 2002; Bartle, 2015; Bloom, 1984; Bruniges, 2005; Dalziel, et al., 2016; Hattie, 2003, 2009; Sweller, 1988, 1999, 2012). Evidence-based practice (EBP) in teaching is a key research direction in current literature (Bruniges, 2005; Centre for Education Statistics and Evaluation, 2017; Masters, 2018; Phillips, McNaught & Kennedy, 2010, 2012; Sweller, Ayres & Kalyuga, 2010), but as previously noted , no gold standard has yet been established to determine the relative quality of different levels of evidence. The lack of an agreed-upon standard is regarded as an inhibiting theoretical factor in advancing evidence-based practice (Cope & Kalantzis, 2015; Eryaman, 2017, pp. 1–19; Means & Anderson, 2013). For example, the work of Bloom et al. (1956) in the formation of taxonomies of learning objectives has a different theoretical basis in terms of evidence quality than that of his later work (1984). The earlier work may be classified as being based on expert opinion, whereas the later corpus of work is based on RCTs, arguably a higher level of quality of research.

The different approaches used in educational research provide impetus towards developing a framework for classifying and categorising the relative value of educational research levels in terms of quality. This process can support the informed selection of the highest quality of educational research by practitioners and by corollary, give a lower priority to practices that have been determined to exert a lesser strengthening effect on learning. Supporting this view, Cook, Smith and Tankersley (2012, p. 496) summarise the logical basis for the identification and application of evidence-based practices in education in terms of three premises:

> Premise 1: The most effective instructional practices and programs produce the highest student outcomes. Premise 2: Scientific research is the most reliable method for determining effective instructional practices and programs. Premise 3: Teachers can appropriately apply practices identified as effective by scientific research. Conclusion: Therefore, the identification and application of practices shown by research to be effective (e.g., evidence-based practices) can improve student outcomes.

2.1.3 Further discussion of evidence-based educational models

Recent research has highlighted a focus on evidence-based practice in education. For example, Connolly, Keenan and Urbanska (2018) summarise and address key challenges related to evidence-based practice, with reference to a meta-analysis of 1017 RCT trials for the period 1980–2016. In addition, Hattie (2003, 2009, 2012), a thought leader in the area of meta-analyses of evidence-based practice in education, has conducted analyses of over 800 studies in order to gain insight into the relative effectiveness of different learning interventions and environments. While Hattie's research has attracted criticism regarding its methodological approach (Bergeron, 2017), it has contributed to an evidence-based research direction in education.

The notion of evidence-based practice in education is clearly a multi-dimensional issue. Two key ideas that support the quest for an evidence-based evaluation in this study framework are:

a. the scholarship of teaching and learning (SoTL) (Bass, 1999; Kiener, 2009)

b. scholarly teaching and learning (Boyer, 1990; Martin, 2007).

SoTL represents the research and publication in peer-reviewed journals of findings based on inquiries into approaches to teaching and learning, as well as learning outcomes. SoTL therefore implies a reciprocal relationship between the practice of teaching and research scholarship. Scholarly teaching, however, represents the application of scholarly findings to teaching environments with the goal of improving them. Scholarly teaching is also implied in the goal of this study to apply evidence-based research findings to learning environments (Richlin, 2001; Richlin & Cox, 2004)

The use of RCTs in education does come with a range of caveats and cautions, since no pedagogy will always have the same effect on all students. In other words, a pedagogical strategy may have been validated through RCTs; however, this does not imply that it can be applied without consideration of a range of other factors that are present within in situ learning environments which are known to be complex and multi-layered (Brown, 1992; Kalyuga, 2007, 2009a, 2009b). By the same token, many effective teaching pedagogies and strategies exist that may not have been evaluated through either RCTs or empirical research and it is not suggested that these pedagogies and strategies should be ignored because of this fact. The driving motivation towards evidence-based practice in teaching and learning is to identify strategies that meet the needs of individual learners at increasingly precise levels. This suggests a shift away from the prevalent one-size-fits-all learning design model used in mass education towards the opposite end of the continuum where practices are personalised and individualised to the needs of learners (Bartle, 2015; Bloom, 1984; Bray & McClaskey, 2015; Department of Education and Training, 2005; Institute for Teaching and Learning Innovation, 2015; Keppell, 2014; Kalyuga, 2007, 2009a, 2009b; McLoughlin & Lee, 2010; Reigeluth, 1995; 1999; Reigeluth, Beatty & Myers, 2017; Reigeluth & Carr-Chellman, 2009). The equivalent practice in medicine would be a medical practitioner having a single treatment for all patients with a specific symptom e.g. experiencing chest pain. The individual history of the patient must be understood to verify a diagnosis and determine the best treatment. This lesson from medical practice can be transferred to educational environments, where caution needs to be exercised with assumptions about outcomes when generic pedagogical approaches are implemented. Bakker and Van Eerde (n.d.) illustrate this point succinctly through an account of a research project that took place in a high school environment, but which illustrates a principle that may be applied in higher education:

> When doing research in an American school, we heard teachers complain about their managers' decision that every teacher had to start every lesson with a warm-up activity (e.g. a puzzle). Apparently, it had been proven by means of an RCT that student scores were significantly higher in the experimental condition in which lessons started with a warm-up activity. The negative effect in teaching practice, however, was that teachers ran out of good ideas for warm-up activities, and that these often had nothing to do with the topic of the lesson. Effectively, teachers therefore lost five minutes of every lesson. Better insight into how and why warm-up activities work under particular conditions

could have improved the situation, but the comparative nature of RCT had not provided this information because only the variable of starting the lesson with or without warm-up activity had been manipulated.

The quest for an evidence-based framework for educational practice is therefore a key research direction and this quest can be informed by similar frameworks in medicine and other research-based disciplines (Hill, 2006).

Other specific approaches to evidence-based teaching and learning have emerged from the literature. For example, Clark (2010, pp. 10–16), a thought leader in evidence-based educational practices, provides a set of useful guidelines as well as caveats for applying evidence-based approaches to education. First, an evidence-based mindset helps to identify and debunk any “myths” that have come into common practice in teaching without being substantiated by evidence, which Clark (2010, pp. 7–23) summarises as follows:

1. Learning styles i.e. the view that learners have fixed modes of processing information during learning (Clark & Feldon, 2005; Kirschner, 2017)
2. Technological panacea i.e. the use of technology per se as contributing to learning (Saunders & Gale, 2011)
3. Students having to “like” learning for it to be effective i.e. the connection between the experience of learning and actual learning that occurs (Clark, 2008, 2010)
4. The universal effectiveness of pedagogical strategies such as gamification or storytelling i.e. the assumption that a “buzz-word” strategy has value without determining the needs or prior knowledge of individual learners (Clark, 2008, 2010).

2.1.4 Levels of research quality in medicine

In contrast with the nascent stage of development of a research evaluation framework for education, levels of evidence quality in medicine have been established through a number of instruments, including: the Canadian Task Force on the Periodic Health Examination's Levels of Evidence; Sackett's Levels of Evidence; Levels of Evidence for Prognostic Studies, Levels of Evidence for Therapeutic Studies; Grade Practice Recommendations (Akonbeng, 2005; Burns, Rohrich & Chung, 2012).

These standards form part of the research quality standards in medicine, also called Evidence-Based Medicine (EBM), defined by Masic, Miokovic and Muhamedagic (2009, p. 219) as follows:

> Evidence based medicine (EBM) is the conscientious, explicit, judicious and reasonable use of modern, best evidence in making decisions about the care of individual patients. EBM integrates clinical experience and patient values with the best available research information. It is a movement which aims to increase the use of high-quality clinical research in clinical decision making.

This demonstrates that evidence-based practice is an ongoing, evolving quest in medicine, curated by central authorities worldwide. Burns, Rohrich and Chung (2012, p. 308) state that:

> The levels of evidence are an important component of EBM [evidence-based medicine]. Understanding the levels and why they are assigned to publications and abstracts helps the reader to prioritize information. This is not to say that all level 4 evidence should be ignored and all level 1 evidence accepted as fact. The levels of evidence provide a guide and the reader needs to be cautious when interpreting these results.

The Cochrane Collaboration provides the most widely accepted quality evaluation system for medical research (Ryan, Prictor & McKenzie, 2013). Moreover, medical research has multiple scales for determining levels of validity of evidence and for validating the reliability, as well as risk of bias, of research at different levels.

Table 2.1 The Cochrane Collaboration model of research evidence quality

Level	Description
1	(Base level) Expert opinion
2	Case studies
3	Cohort studies
4	Randomised controlled trials (RCTs)
5	Critically appraised individual articles (article synopses).
6	Critically appraised topics (evidence syntheses and guidelines)
7	(Highest level) Systematic reviews

Notes: This model defines seven levels of research evidence quality. RCTs represent a high level of research quality (level 4).

Within the Cochrane Collaboration, RCTs occupy one of the highest levels of validity and reliability of research, but other levels of validity exist as well e.g. expert opinion. The analytic tools provided by the Cochrane Collaboration do not imply that all evidence should be based on RCTs, but it does mean that there is transparency regarding the assertions about quality of research made and the basis on which they are made. The recently established Campbell Collaboration (Campbell Collaboration, 2019) was developed as a sister evidence-based model for evaluating research in the arts and humanities, including educational research (Ilic & Maloney, 2014).

In terms of the goals of this study, the concept of a medical research quality standard for evaluating educational research (Evans & Benefield, 2013) has both positive and negative implications. On the positive side, there are factors in medical research evidence that may be usefully adopted in the educational model, such as a hierarchy of rating quality levels of research. On the negative side, even the most rigorous medical research evidence is not a guarantee that a medical intervention will work in the same way for every patient (Akobeng, 2005; Ilic & Maloney, 2014), but requires close monitoring and adjustments of interventions when necessary.

This implies that the individual patient's history is critical to the diagnostic process in order for the medical practitioner to predict with some degree of reliability any risk that may arise.

When this principle is applied to education, it points to the need for a personalised approach to diagnosing the state of the individual learner's level of learning health (Saha & Dworkin, 2009). This means that just as medical practitioners have tools and instruments for gathering evidence to support diagnostic decisions, so teachers also require diagnostic tools to:

a. make the level and quality of prior knowledge of the learner visible, or clearly apparent

b. obtain a thorough understanding of the pathway the learner has taken to reach the current point of development

c. identify barriers to progress that learners are encountering.

The diagnostic metaphor in learning aligns with the construct of triage used in medicine, where medical practitioners engage in a personal, focused intervention with patients in order to determine and prescribe treatments or direct patients at an appropriate level of health care. The construct of triage, when integrated within educational contexts, implies the necessity of a mediative role for the teacher to ensure the state of the learner's progress towards expertise is understood in terms of an objective measurement standard. In other words, the curriculum requires development in terms of parameters of expertise in specific knowledge domains (de Groot, 1965), as opposed to more general pedagogical activities that may have limited relevance to the far transfer of knowledge to authentic learning contexts.

In summary, evidence-based practice in education, by definition, requires an objective and transparent pathway towards expertise by the learner, objective measures of the value of interventions that propel the learning along the pathway to expertise, as well as a method of measuring the learner's progress or lack thereof in both domain knowledge and affective capabilities such as motivation, self-efficacy and other heutagogical factors (Al-Alwani, 2014).

2.1.5 Parallels between evidence-based practice in medicine and education

The reference to a medical model of research quality to inform the quality evaluation of learning has some promising implications. First, it has the potential to transform education at scale. Just as medical practices or procedures may become generally accepted and internationally implemented for the benefit of a high number of patients, so might an objective learning design standard serve as the basis for implementing learning strategies through a systematic, monitored process in order to benefit high numbers of learners (Evans & Benefield, 2013)(see Appendix D).

While a study of this nature will have numerous limitations, it is nevertheless attempting to contribute towards the development of a system built on an evidence-based research foundation that has the potential to address key issues in the quality of learning design and its associated learning outcomes.

The intention behind referencing the Cochrane and Campbell Collaboration models is therefore to use these standards as stepping stones for initiating a more robust process for evaluating learning design standards in education. This model represents a starting point with the intention of continued development as a future research direction.

Regarding a research quality evaluation standard for education, an issue immediately arises, since there are relatively few RCTs related to learning design compared with general approaches to learning. However, where this level of evidence exists in the literature, it could be included to inform learning design in support of strengthening the base of evidence-based practice. Both Greenhalgh (2001) and Sackett and Haynes (1995) concur with the argument that evidence-based medicine represents the strengthening of a clinician’s conventional skills in diagnosing, treating and preventing disease through a systematic approach that frames relevant and answerable questions, with further rigour attained through mathematical estimates of both probability and risk. This conclusion could be extrapolated to educational environments, where evidence-based learning strategies informed by RCTs have the potential to strengthen the skills of educators in advancing learners towards higher levels of expertise in specific knowledge domains.

The medical model of research quality is therefore a useful approach for applying an evidence-based model to education. This research direction has been criticised as a framework that restricts educational questions to issues of “effectivity and effectiveness” and secondly, as limiting opportunites “for participation in educational decision making” (Biesta, 2007, p.1). These criticisms provide insight into the types of risks that may need to be mitigated in pursuing an evidence-based research direction in education. Pursuing this direction does not negate any positive work currently being done by educational researchers in their quest for standards-based learning design; rather, it contributes to the discourse in these areas by examining how teaching may be enhanced by other disciplines through the identification, grouping, classification, collation and systematic application of high-quality research findings (Blumberg, 2011; Boland, Cherry & Dickson, 2014).

2.1.6 Articulating a standard for evaluating the quality of educational research

To this point, an argument has been developed for adopting an evidence-based framework from medicine for determining levels of educational research quality. This argument is underpinned by a survey of approaches to the design–teaching–learning–evaluation cycle, or parts thereof, as well as relevant information regarding theoretical frameworks on which these approaches are based. The outcome of the survey was a specification for the quality levels of educational research and in particular the level of research suitable for this study.

Table 2.2 The research standard adopted for this study (Level 5)

Level	Abbreviation	Title
1	HT	Heuristics or traditional guidelines
2	EO	Expert opinion
3	QB	Quality benchmarking
4	CT	Controlled trials
5	RCT	Randomised controlled trials
6	MS-RCT	Meta-studies of randomised controlled trials (RCTs)

Notes: Table 2.2 represents the standards for rating existing approaches to the design–teaching–learning–evaluation cycle (or parts thereof). It has been derived from Cochrane (1979) and Campbell (2019) models of research quality levels.

Levels 1–3 suggest useful categorisations of research quality, but require further validation within the educational community if widespread consensus and acceptance of a standards framework is to be achieved.

Level 5 reflects the key standard used in medical research and which has been adopted as the first parameter for evaluating research in education while Level 6 (MS-RCT) indicates meta-studies of RCTs.

The categorisation of research quality levels as in Table 2.2 above does not negate the validity of any other possible levels of research quality. The use of this categorisation is to illustrate the range of available categories and to provide a context for selecting Level 5 as suitable for the purposes of the current research study.

Table 2.2 clarifies how the term evidence-based is defined in this study. While multiple levels of research quality have been identified, research based on RCTs has been adopted as a key criterion for evaluating levels of research in education. This is due to the fact that RCTs are considered the gold standard of clinical trials; have been designed to control bias in research findings; are reproducible; have a potentially high level of generalisability; are governed by ethics standards; are reported in peer-reviewed publications for critique and further research; represent a higher level of rigour and research integrity than other approaches and therefore present the possibility of serving as a gold standard for evidence-based educational research (Collins, 2017; Connolly et al., 2017; Connolly, Keenan & Urbanska, 2018; Leppink, Paas, van Gog & van Merriënboer, 2020; Morrison, 2001; Phillips, McNaught & Kennedy, 2010; Styles, 2018; Sweller, Ayres & Kalyuga, 2011).

The literature also identifies challenges in the use of use RCTs in education, but also suggests ways of addressing and overcoming them in order to gain the benefits of RCTs in research. For example Sullivan (2011) suggests that consideration needs to be given to the particular learning environment as not all in situ environments are suited to RCTs, particularly in medical education. In addition, Wozny, Balser & Ives (2018) identify the expenses associated with of large-scale RCTs and experimental design as problematic, but propose a cost-effective model for overcoming these challenges. It has been noted in Chapter 1 that both Bloom (1984) and Sweller (Sweller, Ayres & Kalyuga, 2011) have set precedents for using RCT-based standards in education that have resulted in advances in both the theory and practice of teaching and learning. The following sections investigate educational literature to further support the use of RCTs as a quality standard in this thesis.

2.2 Categories of approaches to the design–teaching–learning–evaluation cycle

Snelbecker (1999, p. 668) observes that approaches to instructional design and learning theories are increasing significantly, therefore signifying the need to develop a "taxonomy" for "classifying currently available theories and recognizing needs for further theory development". While the process of taxonomical development is recognised as challenging due to the variety of purposes different taxonomies may serve, it is posited as a necessary step for advancing the understanding of evidence-based approaches to the design–teaching–learning–evaluation cycle.

Broad classifications of approaches to the design–teaching–learning–evaluation cycle include pedagogy (teacher-led instruction) and andragogy (conditions of learning for adults). A recent additional classification is heutagogy (Hase & Kenyon, 2001) which is defined as self-determined learning capability (see also Mezirow, 1997–Transformative learning). Pedagogy and andragogy reflect approaches with higher levels of teacher direction, whereas heutagogy focuses on self-determined capability levels of the learner (Hase & Kenyon, 2001). In this study, heutagogy has been adopted as an umbrella term for affective factors related to individual learner capability including motivation (Martin, 2016; Paas, Tuovinen, Van Merriënboer & Darabi, 2009; Sweller, 2003), self- regulation (Bachelard, 1934; Franck, Land & Schack, 2013; Paivio, 1971, 1986; 2010; Vrieling, Stijnen & Bastiaens, 2018), learner agency (Nicol, Tsai & Gaskell, 2010; Nowicki & Strickland, 1973), self-efficacy (Bandura, 1997a), perseverance, persistence and other characteristics of learners that contribute to the compound skill of self-directed learning capability (Kahn, Qualter & Young, 2012). Heutagogical factors are assumed to be facets of individual learner profiles that contribute to successful learning outcomes and therefore require acknowledgement and management within learning environments. Pedagogy, andragogy and heutagogy are viewed as a progression of steps towards increasing learner capability, independence and expertise (Blaschke, 2019; Hase and Kenyon, 2001).

Snelbecker (1999) cites a range of attempts to develop such taxonomies, including: Joyce, Weil and Calhoun (2008) who developed a method for the classification of approaches to teaching; Mosston and Ashworth (1990), who posit a classification system based on their model called the spectrum of teaching styles. Scriven (1994) suggests an approach for classifying the core duties and responsibilities of the teacher (DOTT)(Scriven, 1994); finally, the updated version of Bloom's taxonomy (Anderson & Krathwohl, 2001) that may also serve as a classification system for learning objectives.

The method used to seek and classify approaches to the design–teaching–learning–evaluation cycle is that of a scoping review. As previously noted, the aim of this review is to refine the selection parameters for levels of evidence-based practice in education from a theoretical perspective.

2.2.1 Scoping reviews

A full scoping review is a form of knowledge synthesis that addresses an exploratory research question aimed at mapping key concepts, types of evidence, and gaps in research related to a defined area or field by systematically searching, selecting, and synthesising existing knowledge (Colquhoun, et al., 2014, pp. 1292–94). Arksey and O'Malley (2005, p. 1) acknowledge the weakness of a lack of definition of scoping studies in the literature which results in variable depth "depending on the purpose of the review itself". However, for the purposes of this study, "Scoping review design represents a methodology that allows assessment of emerging evidence, as well as a first step in research development" (Peterson, Pearce, Ferguson & Langford, 2016, p. 12).

The purpose of a scoping review in this study, is therefore "to map the key concepts underpinning a research area as well as to clarify working definitions, and/or the conceptual boundaries of a topic" (Arksey & O'Malley, 2005, p. 1). A precedent for a flexible approach of this nature has been set by The Joanna Briggs Institute Reviewers' Manual (Aromataris & Munn, 2020), which asserts that scoping reviews may have a key focus on one of these aims, or alternatively focus on them as a complete set.

The findings of the current survey of approaches to the design–teaching–learning–evaluation process, which is defined as a scoping review (Grant & Booth, 2009) consisted of keyword and combination keyword searches (see Table 2.3) in multiple databases including the following:

1. CiteSeerX (https://citeseerx.ist.psu.edu/)
2. Cochrane Library (www.cochranelibrary.com/)
3. Elsevier (www.elsevier.com/en-au)
4. ERIC (https://eric.ed.gov/)
5. Google Scholar (www.scholar.google.com)

6. IEEE Explore (https://ieeexplore.ieee.org/browse/periodicals/title)
7. J-STOR (www.jstor.org/)
8. Questia (www.questia.com/)
9. LearnTechLib (www.learntechlib.org)
10. Sage (https://journals.sagepub.com/)
11. Science Direct (www.sciencedirect.com/browse/journals-and-books)
12. SpringerLink (https://link.springer.com/)
13. Taylor & Francis Online (www.tandfonline.com/)
14. ProQuest (www.proquest.com/libraries/academic/databases/)
15. PsychInfo (www.apa.org/pubs/databases/psycinfo/).

In addition, the above review was expanded by searches in various university and TAFE libraries were accessed (deakin.edu.au/library; Box Hill Institute Group (https://studentweb.bhtafe.edu.au/library) and Holmesglen (https://holmesglen.sirsidynix.net.au); Researchgate.com was accessed as a supporting reference database; experts, researchers, supervisors and colleagues were contacted to request reference works on specific topics; moreover, reference sources were identified from conference proceedings, presentations, informal discussions and the three focus groups conducted for this study.

Key search terms and keyword searches resulted in identifying over one hundred and sixteen approaches that have informed the design–teaching–learning–evaluation cycle spanning over a century; as a result, the literature review is based on research findings over a 135-year time period from 1885–2020 (see Appendix E).

The specific search criteria included key words derived from references within the literature, key-word mining in research databases, and cross-references within peer-reviewed journal articles and books. Boolean operators (and/ or) were used as search criteria in order to combine search terms.

Table 2.3 Keyword search terms used in this study

Column A	Column B
Learning	Design
Teaching	Approaches
Learning design	Methods/methodologies
Instructional design	Paradigms
E-Learning/eLearning	Frameworks
Education/al	Guidelines
Evaluation	Principles
Evidence-based	Models
Validated	Checklists
Researcher name (e.g. Bloom, Sweller)	Databases
Assess/ment	Matrices
and/or (Boolean operators)	Processes
Evidence-based practice	Systems

Notes: Keywords and keyword combinations used as search terms in the scoping review, the selected format for literature review. Terms from Column A and B were used individually and in combination.

2.3 Inclusion and exclusion criteria, search protocols and coding

As the goal of the scoping review was the identification of the relative quality of evidence-based approaches to the design–teaching–learning–evaluation cycle, inclusion criteria for the search incorporated peer-reviewed journals and scholarly publications by published experts. In addition, late 19th and early 20th century research that was validated through peer review were also included. For example, the approach to learning posited by Ebbinghaus (1885) and other early researchers fell into this category.

As key researchers were identified in the literature, their names were added to searches. For example, the Dreyfus and Dreyfus (1980) model of expert acquisition was first encountered in an article, then followed by a search in a range of databases.

Where possible, sources based on repeated, validated experiments were sought i.e. RCTs, or controlled trials; for example, the controlled research experiments by de Groot (1965) on long-term memory functions were later replicated by Chase and Simon (1973a); research on schema-based learning by Bartlett (1932) was later experimentally validated by Sweller (1988, 1999); Sweller, Ayres and Kalyuga (2011) cite a broad range of RCT-based experiments to validate and interpret CLT effects (Tindall-Ford, Agostinho & Sweller, 2019). The exclusion search criteria encompassed non peer-reviewed sources, or sources that could not be confirmed or validated as originating from English, peer-reviewed research. Where there was doubt regarding the validity or completeness of information, cross-referencing within peer-reviewed sources and publications by expert researchers was conducted; non-referenced or incomplete sources were excluded.

Informal sources such as websites, blogs and other formats were excluded unless approaches could be validated in peer-reviewed or expertly-validated sources. For example, web-based writings containing criticisms of CLT were excluded, whereas criticisms within peer-reviewed sources were referenced; finally, writings about the life and achievements of researchers in websites were validated through cross-referencing with peer-reviewed sources.

2.4 Targeted search for existing approaches to the design–teaching–learning–evaluation process

Approaches to learning design, as represented in the design–teaching–learning–evaluation cycle, from ancient and historical texts, also emerged from this literature review. Historical approaches are acknowledged as representative of the longevity of the notion of learning design and the deep roots of the quest for intentionally structured learning for improved learning outcomes in recorded human history. Historical texts set the context for systematically reviewing approaches to learning from the 20th century onwards, but are beyond this scope of this study.

2.5 Approaches to the design–teaching–learning–evaluation process organised into categories

This section consists of a review of approaches to learning design that have been identified in contemporary educational literature according to the search criteria specified in Section 2.3. The literature review revealed numerous learning theories and models of evaluation compiled as written volumes (Reigeluth, 1995, 1999; Reigeluth, Beatty and Myers, 2017; Reigeluth & Carr-Chellman, 2009; Snelbecker, 1999). However, narrative approaches of this type have not been useful in obtaining a succinct overview of learning design strategies in order to understand how approaches relate to each other, to determine gaps for possible future research directions, or to apply these strategies systematically within in situ learning environments. For this reason, the results of this review have been organised into 19 taxonomical categories.

All the surveyed approaches in Table 2.4 represent artificial constructs for informing the design–teaching–learning–evaluation cycle or parts thereof. Some overlap of categories is inevitable. For example, the two categories of constructs and guidelines may have some shared meaning. However, these categories are advanced as a contribution to the cataloguing of approaches to learning that may be extended as a future taxonomical research direction beyond this study.

The nominated categories are suitable for addressing the current research investigation. The identified approaches fall within a continuum. Simple approaches represent partial aspects of the design–teaching–learning–evaluation process, such as checklists, guidelines, heuristics, and theories. More complex approaches include models and frameworks that are increasingly holistic in terms of the full design–teaching–learning–evaluation cycle. The purpose of this taxonomic structure is to demonstrate how CLT emerged as a framework for informing the development of CLEMS.

Appendix E contains a summary of identified approaches in each taxonomical category represented in Sections 2.6.1–2.6.19 below.

Table 2.4 A suggested taxonomic summary of the literature review findings

Number	Taxonomical category	Quantity
1	Checklists	5
2	Constructs	10
3	Effects	1
4	Frameworks	12
5	Guidelines	7
6	Instruments	2
7	Matrices	1
8	Meta-analyses	1
9	Methods	1
10	Models	35
11	Paradigms	4
12	Resources	2
13	Rubrics	3
14	Standards	5
15	Strategies	1
16	Systems	5
17	Taxonomies	9
18	Theories	6
19	Tools	3
	TOTAL	**113**

Notes: Table 2.4 lists 19 categories of approaches to the design–teaching–learning–evaluation cycle identified in the literature review. While this classification is not comprehensive due to the enormous number of existing sub-categories, it provides a useful background context for the development of CLEMS.

The following sections define each category of the taxonomy, with detailed supporting information for each category provided in Appendix E.

2.5.1 Checklists

Checklists represent a pragmatic approach to learning design. They consist of lists of prescriptive criteria for designing or validating the quality learning interventions and environments based on pre-determined selection criteria. Typically, checklists do not include explicit rationales or underpinning theoretical models. Some checklists have been derived through research (Guidy-Olai, 2009; Moore, 2015), best practices (Academic Senate for California Community Colleges, 1999; Culatta, 2018; Merrill, 1983) or benchmarking

(Quality Matters, 2017) while others are compilations by educators that have been published to communities of learning on blogs (Moore, 2015) but may not have not been subjected to any rigorous validation process using RCTs.

The usefulness of checklists may be their ease of accessibility and useable format for immediacy of application by time-poor teachers or educational stakeholders; however, they are not generally based on a common frame of reference with regard to defining quality standards.

Checklists may therefore be characterised as much by what they include as well as by what they omit in terms of personalised, context-specific learning design principles, demonstrating the bespoke nature of checklists in fulfilling specific localised needs. Moreover, the varied nature of checklists demonstrates the lack of an agreed (or gold) standard for criteria selection related to the quality of underpinning research.

2.5.2 Constructs

Constructs represent unobservable psychological notions in concrete terms, using representations or other semiotic devices (Fried, 2017). In addition, constructs may be psychological concepts that include attitudes, motivations and emotions. For example, personal construct theory (Kelly, 1963) is an example of a theoretical perspective on the way people make sense of their experiences or realities. Kelly (1963, pp. 69–70) defined the term construct as follows:

> we use the term construct in a manner which is somewhat parallel to the common usage of 'concept' … We have included, as indeed some recent users of the term 'concept' have done, the more concretistic concepts which nineteenth century psychologists would have insisted upon calling 'percepts' … we also see our construct as involving abstraction – in that sense our construct bears a resemblance to the traditional usage of 'concept'.

Constructs are generally conceptually rich approaches to the design–teaching–learning–evaluation cycle, but non-prescriptive in terms of pedagogy. Nevertheless, constructs represent a fertile source of ideas for advancing both theory and practice of education through hypotheses, as they connect ideas and conjectures that may lead to new lines of enquiry. Constructs resemble theories, conceptual models or explanatory variables that are not directly observable (Phan, 2013). Examples of constructs are visible learning (Hattie, 2009, 2012), the black box of cognition (Hamlyn, 1990; Grant, 1992) and the spiral curriculum (Bruner, 1960). Multiple intelligences (Gardner, 1983, 1993; McInerny, 2014) is a construct that encourages educators to recognise that all students have intelligences that might not be measurable on traditional or standardised tests. Some constructs may also align with theories, guidelines or other categories of learning design approaches.

Using factor analysis, or a similar process numerous constructs may be compared and classified for the evaluation of learning design in order to combine similar ideas, eliminate duplication of ideas and prioritise ideas in terms of their relevance. For example, a range of constructs relevant for addressing the problem of this study has been analysed and synthesised. These include the information-age technology construct (Reigeluth, 1999), systems thinking (Bertalanffy, 1968; Mingers, 2004), double-loop learning (Argyris, 1983, 2002, 2005) and CI (Deming, 1986; Bhuiyan & Baghe, 2005). A potential weakness of applying constructs in practice is that while they provide useful analogies and metaphors for informing learning design, they may lack the predictive qualities of an evidence-based theory from which principles might be abstracted for general application.

2.5.3 Effects

Effects are a special class of approach to the design–teaching–learning–evaluation cycle as they represent models of learning derived from hypotheses, conjectures or problems that need to be addressed. Effects provide insight into the underpinning mechanisms present in learning environments and may suggest strategies for increasing the effectiveness of learning. For example, early effects referenced in educational literature include the Hawthorne effect (Draper, 2018; French, 1953) which explained changes of behaviour in factory workers due to their knowledge of being observed. Additionally, the Pygmalion effect described the impact of teacher expectations on learning outcomes (Rosenthal & Jacobson, 1968). Effects arising from CLT explain learning in terms of the structure and functions of human cognitive architecture and how the mechanisms of working memory and long-term memory are engaged during learning (Sweller, Ayres & Kalyuga, 2011). The deepened understanding of learning gained through the investigation of effects presents opportunities for devising strategies that could improve learning environments. In addition, effects may give rise to hypotheses for investigating educational phenomena and result in the generation of new knowledge through ongoing experimental testing and validation. For example, an emergent effect in educational research is stereotype threat, where people in learning environments are at risk of underperforming academically due to living up to negative stereotypes about their group (Fraser & McLoughlin, 2018; Steele, 2010; Steele & Aronson, 1995).

2.5.4 Frameworks

Frameworks represent larger theoretical constructs that demonstrate the interrelationships between its components. In education, frameworks may reflect earning theories or may posit hypothetical models for advancing the field of learning design. In addition, frameworks may represent technological architectures and systems for managing the design–teaching–learning–evaluation cycle, processing data and generating analytic reports.

Frameworks represent complex, multi-faceted processes with interacting elements and components at multiple levels and are underpinned by assumptions regarding learning and learning management processes. Technological frameworks and systems are outlined in Section 3.2.14.

The plethora of available educational frameworks demonstrates the need for clarification of learning and learning management processes; it also demonstrates the lack of a standardised approach to the design–teaching–learning–evaluation cycle.

2.5.5 Guidelines

Guidelines may provide a more detailed approach to learning design than checklists and may have a stronger link to underpinning theoretical models. Guidelines are a well-represented category of approaches to learning design (and can include a range of formal or informal procedural formats.

2.5.6 Instruments

Instruments represent a broad category of approaches to the design–teaching–learning–evaluation cycle. For example, instruments may relate to some or all of these four stages and may be constructed with broad or narrow objectives. In its broadest application, an instrument may be defined as any designed artefact, questionnaire, test, examination, checklist, rubric, or tool, whether simple or sophisticated, paper-based or digital.

Instruments may be designed for use at policy level (Hannaway and Woodroffe, 2003) or at any other level of the educational cycle; or instruments may be represented as sophisticated systems (Feuerstein & Jensen, 1980).

2.5.7 Matrices

Matrices express complex ideas and relationships between ideas using multi-axis parameters that define a unified framework. For example, Johnsen et al. (2011) describe a matrix that is learner-oriented and which:

> gives a focus for discussion and an overview of an institution's educational outcomes. On one axis of the matrix, common educational outcomes are listed: knowledge, technical skills, critical thinking, ethical and professional values, patient and practice management, and social responsibility awareness. On the other axis, methodologies are listed: definition, cultivation strategies, measures (summative/formative, objective/subjective), institutional coordination, and competency determination. By completing the matrix, an overview of the process by which students reach these outcomes emerges.

Matrices express unified relationships between components, serving as a useful construct for collating the disparate research arising from CLT. For example, applying principles of three-dimensional matrix structures could demonstrate relationships between the learner's prior knowledge level, new learning levels and cognitive load management strategies. The reviewed matrices do not reference a model of human cognitive architecture, but focus on derivative functions of the learning process.

2.5.8 Meta-analyses

Meta-analysis has been described by Haidich (2010, p. 29) as "a quantitative, formal, epidemiological study design used to systematically assess previous research studies to derive conclusions about that body of research". Furthermore, meta-analyses are beneficial due to the process of consolidating and collating extensive and frequently complex literature findings to support evidence-based conclusions and designs.

While meta-analyses may serve a useful purpose in identifying characteristics and trends within research (Hattie, 2009, 2012), they are usually not prescriptive in terms of the specific pedagogical strategies that educators may use to achieve stronger learning effects for individual learners. To obtain a more detailed view of the specific pedagogical strategies used in each of the identified paradigms, additional searches would need to be conducted.

2.5.9 Methods

Methods are prescribed approaches that provide guidelines or principles for achieving specific learning outcomes and may occur at a micro level (using instructional procedures), or at a macro level (using a specific set of procedures that constitute a system or approach to teaching a subject). Methods usually have a prescriptive or ordered structure. For example, methods of musical instrument instruction by Czerny (1983a, 1893b) for piano instruction and for guitar instruction (Sor, 1832) represent two early methodological approaches to learning. In many medical teaching institutions, Problem Based Learning (PBL) has been adopted as a standard method of instruction (Barral & Buck, 2014). Methods describe a broad range of systematic approaches to instruction and may vary based on philosophical or pedagogical assumptions. The relevance of methodological approaches is critical to this study as the research question centres on a method of collating, distributing, managing and monitoring the pedagogical effects arising from CLT.

2.5.10 Models

Models may express external systems or processes, for example a model of the mechanical processes in a car engine, or may express the mentally formed representations of such systems or processes by individual learners. Models therefore represent a unified cluster of ideas that are linked through an organising principle and "mental models are internal representations of systems in a particular knowledge domain" (Staggers & Norcio, 1993, p. 587).
Representation of models may include flow-charts, interacting parts of systems, hierarchical structures, or concentric circles representing levels of importance of concepts. They may represent simple or highly complex conceptual relationships between ideas and are designed to simplify understanding, helping to "understand, explain, predict, and act" (Page 2016). The significance of mental models and their representations to this study are that the maturity level

of learners' representations relate to levels of understanding of domain knowledge and are therefore aligned with the construct of schema formation and automation (Sweller, 1988). In addition, models provide some level of predictability that are most useful for evaluating learning design due to their generalisability. For example, the model of human cognitive architecture posited by CLT enables predictive hypotheses about learning to be generated and tested through empirical research.

2.5.11 Paradigms

Educational paradigms represent the larger frameworks, structures or constructs that inform the design–teaching–learning–evaluation cycle. Four major educational paradigms have set the background to the current research project: behaviourism, cognitivism, constructivism and connectivism, each informed by a substantial base of formal research. Paradigms may also represent sub-frameworks, for example, mass education vs. personalised education (Bartle, 2015). Or industrial-age education vs. information-age education (Reigeluth & Carr-Chellman, 2009).

2.5.12 Resources

Resources in the context of this study represent search engines and databases, as well their contents, that provide access to information on learning design. Resources may also include: white papers, for example the New Media Consortium Horizon Report (2012, 2015, 2016), declarations, for example The Cape Town Open Education Declaration (2007) and the Larnaca Declaration on Learning Design (2013), discussion papers (Bartle, 2015), or insight papers (Masters, 2018) that guide or reflect on learning design at a strategic level to advance a particular approach such as personalised learning.

While this category is generic, it represents points of access for obtaining more specific classifications of knowledge based on search criteria. For example, this literature review was identified from these resources using keyword searches for accessing specific research and auxiliary information related to learning design.

2.5.13 Rubrics

Rubrics represent sets of evaluation criteria that support the grading, rating, or evaluation of specific aspects of quality. Rubrics may represent a process for evaluating both learning design and learner achievement outcomes. Mertler (2000, p. 1) defines rubrics as:

> rating scales – as opposed to checklists – that are used with performance assessments. They are formally defined as scoring guides, consisting of specific pre-established performance criteria, used in evaluating student work on performance assessments. Rubrics are typically the specific form of scoring instrument used when evaluating student performances or products resulting from a performance task.

As a ubiquitous evaluation strategy, rubrics may reflect a variety of approaches which have been disparately developed by individuals and institutions. As a result, rubrics may or may not be derived from evidence-based research and therefore may be limited in applicability to specific learning programs, courses, or teaching environments. This does not imply that the evaluation criteria specified by rubrics are invalid within these specific environments.

2.5.14 Standards

Learning design standards are usually developed by institutions, controlling bodies or government organisations and may be associated with obligatory compliance, accreditation and legislative requirements. For example, the Australian Government Department of Education, Skills and Employment specifies standards in the form of units of competency within a criterion-referenced framework for vocational education (Australian Department of Education and Training, 2017).

Technical standards e.g. Learning Tools Interoperability (LTI), Shareable Content Object Reference Model (SCORM), or Experience Application Program Interface (xAPI) contribute to the cross-platform shareability of educational resources as well as the technical protocols for sharing these resources, with the aim of improving internal consistency and standardisation of learning environments. Standards therefore play a critical role in informing the distribution of learning programs across different systems at scale. Based on the key word search criteria, the development of standards based on specific cognitive functions for informing learning design have only recently emerged in terms of their contribution to the literature on standards on a broader scale within Australia, and to a limited extent globally. One intended contribution of the current study is to further advance this nascent trend.

2.5.15 Strategies

Strategies in formal learning environments include any teaching methods which have the objective of achieving learning aims, goals or outcomes. Strategies are ubiquitous in multimedia or classroom teaching environments (Brown, 1992) and may be informally derived or the result of rigorous experimental testing, such as RCTs (Bloom, 1984; Sweller, Ayres & Kalyuga, 2011). The University of Leicester (2020) has collated the following useful categories of teaching strategies for higher education:

- large groups (lectures)
- facilitated small groups
- students demonstrating in practical classes
- massive open online courses (MOOCs)
- flipped classroom; active learning (students in charge of their own learning)

- problem based learning
- work based learning
- blended learning and student-led learning.

These categories of strategies represent high-level processes, whereas strategies arising from CLT are focused on the micro-processes of aligning learning with the structure and functions of human cognitive architecture (Sweller, Ayres & Kalyuga, 2011).

2.5.16 Systems

Systems are described as "a set of connected things or devices that operate together" (Cambridge Dictionary, 2018; Rouse, 2005), or "a set of things working together as parts of a mechanism or an interconnecting network; a complex whole" (see www.lexico.com). Information Systems (IS) are defined as sets of interconnected technical or digital components designed to collect, organise, process, monitor, store, distribute and report on information with the aim of supporting decision-making processes, control and quality in organisations. Information systems may comprise software, hardware as well as local and wide-area networks (Bertalanffy, 1968; Bourgeois, Smith, Wang & Mortati, 2019; Branson et al., 1976; Brusilovsky, 2003; Carlsson, 2004, 2010; Gregor & Jones, 2007; Hevner, 2007; Jantsch, 1973; Rogers, 1962; Wynn & Williams, 2012).

Systems therefore consist of multiple interconnected components and may be based on the theoretical construct of Systems Thinking (Bertalanffy, 1968) which is a discipline in its own right; alternately, systems may describe simple, intersected processes that are designed to operate together. Systems may occur naturally (ecosystems), be artificially constructed (Marcus & Silver; Mingers, 2004; Sturm & Sunyaev, 2019) or engage biomimicry or biomimetics, in which "biology can inform technology at all levels" (Vincent, 2009, p. 921). In education, learning management systems (LMSs) are digital systems that extend the capabilities of organisations and educators to distribute learning and training courses, as well as to track, monitor learner progress and communications through learning analytics (Atif, Richards, Bilgin & Marrone, 2013). The ubiquity of digital technologically enabled learning environments (DTELEs) is accepted as a factor within educational environments in the current era and online searches identify hundreds of learning management systems. This category could have its own taxonomic sub-classification system due to the massive volume of systems and the varied approaches they represent (DeBattista, 2018; Hawley, 1997; Reigeluth, 1995, 1999; Reigeluth, Beatty & Myers, 2017; Reigeluth & Carr-Chellman, 2009).

2.5.17 Taxonomies

Taxonomies represent schemes for identifying, describing, classifying and ranking information. Originating in the discipline of biology with Linnaeus (1753), taxonomies represent a systematic approach to organising information e.g. the Linnaean system of biological classification. The study of taxonomy is also a scientific discipline in its own right that includes the analysis and comparison of taxonomies from different disciplines. For example, Bloom et al., (1956) posited a taxonomy of educational objectives in the cognitive domain, which was later revised by Anderson and Krathwohl (2001). Bloom's taxonomy was derived from the model posited within the Linnaean taxonomic structure.

While Bloom's taxonomy has become a key reference in terms of learning design, taxonomies of educational approaches, systems and paradigms are generally in a nascent state in terms of development in the literature. As demonstrated in the current attempt at taxonomic classification, the tendency in education is to generate a plethora of approaches to the design–teaching–learning–evaluation cycle rather than to focus efforts on standardising a body of knowledge. The advantages of developing taxonomies of educational approaches include identifying commonalities between approaches, grouping similar approaches in order to eliminate the duplication of research, and contribute towards establishing core, validated, evidence-based approaches to teaching, learning and evaluation.

2.5.18 Theories

A theory is an explanation of complex phenomena that has the capability of generating hypotheses and predictions (Crotty, 1998; Sarid, 2018). Learning theories comprise a large group of constructs for informing learning design and may have considerable overlap with frameworks or paradigms, models, and standards (Taylor & Hamdy, 2013). Theories may vary from empirically validated constructs to expert opinions or notions that assist in framing aspects of education. This taxonomical category represents the most comprehensive identified in the literature review and is one of the largest categories of approaches to the design–teaching–learning–evaluation cycle.

Theories represent a range of approaches, including empirically validated principles (Mayer, 2005; Sweller, 1988) based on a model of human cognitive architecture, to metaphors of learning such as the spiral curriculum (Bruner, 1960), Reigeluth's (1999) elaboration theory that suggest structures of instruction and learning environments, to approaches to adult learning (Aronson & Briggs, 1983; Gagné, 1968, 1985; Knowles, 1984a, 1984b).

Wacker (1998) provides an insightful definition of a theory through the following points:

- theories should inform practice
- theories should comprise conceptual definitions, domain limitations, relationship-building, and predictions
- theory building is relevant since it provides an analytical framework for research
- theory building facilitates the ongoing development within a discipline
- theory building is required for the applicability of interventions to practical, real-world problems

- to be useful, a theory must follow the virtues (or criteria) for ‘good’ theoretical formation, including characteristics that align with effective research methods, including: uniqueness; parsimony; conservation; generalisability; fecundity; internal consistency; empirical riskiness; and abstraction.

Popper (1959, p. 112) observed that “theories may be more, or less, severely testable; that is to say, more or less, easily falsifiable. The degree of their testability is of significance for the selection of theories”.

The emergent suggestion from this category is that theories present the potential for informing learning design from an evidence-based perspective, especially theories that have higher levels of testability. Both CLT and its extension into the Cognitive Theory of Multimedia Learning (CTML) fall into this category. They contribute specific strategies, present clear instructions for their implementation as well as their predicted conditions of applicability, all of which are testable. Based on RCT experiments, these theories use a unified model of human cognitive architecture to derive learning strategies from the known limitations, strengths, functions and interrelationships between memory systems during learning.

CLT and CTML therefore offer a promising research domain for contributing to the development of an evidence-based learning design evaluation instrument.

2.5.19 Tools

Tools may encompass a broad range of approaches to the design–teaching–learning–evaluation cycle e.g. questionnaires, quizzes, or rubrics, learning objects (Kay, 2011) or authoring applications such as Adobe (adobe.com), or Articulate (articulate.com) products. Tools may be digital or manually administered, in the form of guidelines or procedures, or represent any construct or intervention that has the goal of increasing the efficiency of processes in the educational cycle within formal learning environments such as matrices, resources, checklists or guidelines. As a result, there is extensive overlap between tools and the other categories within the taxonomy.

2.6 Clarifying the characteristics of the Information Age model

The categorisation of approaches to the design–teaching–learning–evaluation process within a taxonomical framework serves as a step towards identifying levels of quality of educational research and practice, as well as identifying a suitable technological framework for CLEMS. As previously noted, research arising from RCTs represents a key selection parameter for developing CLEMS. In the early stage of research the use of CLT was not a foregone conclusion, but emerged as a suitable framework for developing CLEMS based on indicative factors arising from the research base of cognition.

Mayer (2005, p. 22) reinforced the significance of using a cognitive model for evaluating learning:

> Research on learning shows that meaningful learning depends on the learner's cognitive activity during learning rather than the learner's behavioral activity during learning. You might suppose that the best way to promote meaningful learning is through hands-on activity, such as a highly interactive multimedia program. However, behavioral activity per se does not guarantee cognitively active learning. It is possible to engage in hands-on activities that do not promote active cognitive processing.

The usefulness of such a standard is twofold:

a. as previously noted, it can limit the use of fad strategies in teaching (R.C. Clark, 2010, pp. 8–9; Willingham, 2012) that are driven by factors other than substantiated evidence, and replace them with strategies that facilitate cognitively active learning

b. it can introduce evidence-based strategies to replace unguided or minimally guided approaches such as discovery learning and other search-based approaches that have been established as poor learning strategies for novices (Kirschner, Sweller & Clark, 2006).

The selection of an approach to learning design that may be used as an evidence-based evaluation standard has some specific requirements. For example, evidence-based principles of learning design need to be identifiable and quantifiable in order to be validated (Wiggins & McTighe, 2005). In the analysis of approaches CLT was ratified as a theoretical framework that provided a cogent set of evidence-based learning strategies for incorporation as an evaluation standard into CLEMS based on the two selection criteria. Moreover, the notion of an information-age system emerged, which has been in the literature since the 1990s (Reigeluth, 1995; Reigeluth, 1999, pp. 17, 94; Reigeluth, Beatty and Myers, 2017, pp. 2, 12, 16, 70–71; Reigeluth & Carr-Chellman, 2009, pp. 391–399) and represents a paradigm shift in the way in which learning is delivered and evaluated. The information-age learning technology construct presents an open-ended model that provides flexible options for translating theoretical notions into practical functions, thereby offering the possibility of bringing theoretical models into practice. The flexibility of an information-age framework could also include functionalities for data processing and generating relevant reports that provide educators with information for informing learning design with more precision. The information-age model therefore represents a "technology-centred approach" to learning that "focuses on how to incorporate emerging technologies into instruction and on which technology is most effective in presenting information" (Mayer, 2005, p. 15). In short, the information-age construct supports the use of technological architecture that has the capability of implementing and tracking the full design–teaching–learning–evaluation cycle.

In terms of this study, the usefulness of the information-age construct is that it represents a framework for integrating disparate features and functions that research has shown to strengthen learning, particularly those arising from CLT. In Chapter 1 a system was articulated for facilitating information-processing capabilities such as analysing, processing and reporting on levels of evidence-based practices in learning environments. This suggests that the information-age concept is well-aligned with the intended functions of the envisaged instrument, which would be conceptualised to process learner information, research data, course and learner capability evaluations, as well as other data sets.

Table 2.5 below describes seven guidelines that have been distilled from the literature review to this juncture for defining the characteristics of an information-age evaluation framework within a theoretical framework of CLT in order to address the problem in this study. The table demonstrates the usefulness of the information-age construct for unifying the themes, characteristics, features and functions that have been identified and discussed to this point.

Table 2.5 Information-age (IA) characteristics of the proposed new evaluation instrument (CLEMS)

Parameters/Characteristics	
1. Theory-based	Has the functionality within a database-driven architecture to collate selected measurement parameters that have been derived from a theoretical framework (Sweller, 1988) supported by empirical (evidence-based) research using RCTs (R.C. Clark, 2010; Sweller, 1999; Sweller, Ayres & Kalyuga, 2011; Tindall-Ford, Agostinho & Sweller, 2020) for evaluating the quality of learning design.
2. Personalised	Is built on a model that takes personalised design–teaching–learning–evaluation pedagogical strategies into account (Bartle, 2015); supports learning designs that are explained in terms of underpinning cognitive mechanisms (Sweller, 1988); includes strategies that have been validated and applied in multimedia environments (Mayer, 2005).
3. Full cycle	Incorporates a full-cycle, iterative process of the design–teaching–learning–evaluation process within a scalable, systematised, technological framework (Reigeluth, 1995; Reigeluth, 1999, p. 17, 94; Reigeluth, Beatty and Myers, 2017, p. 2, 12, 16, 70–71; Reigeluth and Carr-Chellman, 2009, pp. 391–399); harnesses the potential of cloud-based, database driven technologies for managing the design–teaching–learning–evaluation process.
4. Analytics	Incorporates visualised analytic reports of learner progress towards learners increased levels of expertise (Bruner, 1960; Kalyuga, 2007, 2009a, 2009b; Kalyuga, Rikers, Paas, 2012) in domain-specific areas, as well as heutagogical capability (Hase and Kenyon, 2001), where heutagogy is defined as self-determined learning capability. Heutagogy aligns with the recent research direction into the self-management effect, where learners apply principles of cognitive load theory to learning materials “that are non-cognitive load theory compliant”) particularly the split-attention and redundancy effects (Mirza et

	al., 2020, p. 157).
5. SoTL, scholarly teaching and double-loop evaluation	Is built on a framework that supports both the scholarship of teaching and learning (SoTL) (Bass, 1999; Kiener, 2009), scholarly teaching and learning (Boyer, 1990; Martin, 2007) (Appendix A), as well as a double-loop (Argyris, 1983, 2002) evaluation process, defined as evaluating learner outcomes as well as the learning designs used to attain these outcomes (Boyer, 1990; Smith 2001; Felten & Chick, 2018; Shavelson & Towne, 2002).
6. Criterion-referenced model	Includes an expertise/skills-based, criterion-referenced teaching model (Bloom, 1968, 1984; Chandler & Sweller, 2003; Ericsson, 1988; Ericsson, Charness & Feltovich, 2006; Ericsson, Krampe & Tesch-Romer, 1993; Gobet, 2000, 2005, 2016; Kalyuga, 2007; Kalyuga, Ayres, Chandler & Sweller, 2003) where learning outcomes are designed to be in alignment with learning interventions (Biggs & Tang, 2011) and both are aligned with the structure and functions of human cognitive architecture; in addition, CLEMS accommodates flexible time parameters that foster the mastery of personalised learning interventions by learners, termed "nodes of expertise" (NOE), a term coined for use in this study.
7. Adaptive model	Incorporates an adaptive teaching (Kalyuga, 2009a, 2009b) model that aligns and dynamically adapts the individualisation/ personalisation of learning to the needs of learners including: prior knowledge levels, cultural background, social considerations, cognitive, affective, vocational and aspirational factors (Bartle, 2015).

Notes: Summary of emergent characteristics of the new IA evaluation instrument. Identified characteristics to this point of the study have been explained and elaborated to provide a holistic view of the key characteristics and functions of CLEMS that later developed into CLEMS. This table represents the first convergence of themes informing the development of the new instrument.

2.7 Summary

The literature review to this point has brought paradigms, principles and themes to light that contribute to a specification of a new evaluation instrument for addressing the challenges articulated in Chapter 1. This chapter began with an introduction to evidence-based features of medical research and other disciplines. In particular, the Cochrane and Campbell Collaborations were used as a source of reference to establish the first criterion (RCTs) for determining the level of quality of approaches to the design–teaching–learning–evaluation cycle.

More than one hundred approaches to the design–teaching–learning–evaluation cycle were identified and classified into a taxonomy of 19 categories (Table 4). The general characteristics of each category were discussed, with the reviewed examples summarised in Appendix E. Some overlap of definitions between classification categories was observed. The IA construct was determined as suitable to serve as an organising principle for relevant features and functions of a new learning design evaluation instrument.

The advantage offered by approaches to the design–teaching–learning–evaluation cycle that were derived through RCTs, and those that were derived by other means, included:

a. higher levels of research quality and rigour i.e. RCTs suggest a higher level of predictive reliability in determining appropriate pedagogical practices
b. providing validated strategies for use as a standard for evaluating learning design.

In contrast, approaches to the design–teaching–learning–evaluation cycle that are not RCT-based have a lower level of both research rigour and predictive characteristics than RCT-based research for the purposes of this study.

Based on the taxonomy of approaches identified in this chapter, Cognitive Load Theory and its extension into the Cognitive Theory of Multimedia Learning emerge as a promising framework for informing the development of a learning design evaluation instrument within an IA framework. This is due to CLT and CTML being based on RCT research, thus meeting the key requirement for the evidence-based standard articulated in Chapter 1. The cognitive paradigm that underpins CLT and CTML is further investigated in Chapter 3 as part of a historical overview of the four key educational paradigms that arose during the twentieth century.

Chapter 3 – Literature Review: Part B

Historical Educational Paradigms

3.1 Introduction

This chapter investigates the larger, historical paradigms from which the broad range of available approaches to the design–teaching–learning–evaluation cycle have emerged, as summarised in Chapter 2. The purpose of this chapter is to provide the historical context of the cognitivist paradigm and its role in evidence-based educational theory and practice.

3.2 Roadmap of this chapter

Sections 3.3–3.6 provides an outline of four theoretical paradigms that have risen to prominence in educational research during the 20th century: behaviourism, cognitivism, constructivism and connectivism (Siemens, 2005; Duke, Harper & Johnson, 2013). These four paradigms constitute the major frameworks that both position and animate the discourse on learning theory and practice in this study.

The key features of each of these major paradigms will be discussed, their implications for learning design outlined, and criticisms of them will be considered. The section concludes with a discussion regarding the relevance of these paradigms to the problem of evaluating the quality of learning design, concluding with validating arguments for adopting the cognitivist paradigm as the most relevant source of evidence-based practice for this study.

3.3 Behaviourism

John B. Watson (Watson, 1924) is attributed as the founder of modern behaviourism (Begelman, 1980) which “attempts to find the principles underlying changes in behavior. Behavioristic psychology attempts to formulate, through systematic observation and experimentation, the generalisations, laws and principles which underly man’s behavior”

(Watson, 1924, p. 5). In its application to education, behaviourism deals with observable phenomena. It gives no credence to internal or introspective processes that are not outwardly visible as being significant to the learning process (Kant, 1963, originally 1781; Malone, 2017). Watson's article (1913) was a key catalyst for behaviourism becoming an academic discipline in its own right. This article later became known as the "behaviorist manifesto" (Rakos, 2013).

Watson is strongly associated with educational behaviourism and child development. His work forms part of a greater corpus of research associated with influential educational theorists including Skinner (1904–1990), Dewey (1859–1952), Titchener (1867–1927), Thorndike (1874–1949) and others (Araujo, Saraiva, de Carvalho Neto, 2019). While a complete study of Watson's theoretical perspectives is beyond the scope of this study, Watson's notions of behaviourism occurred within a fertile research context that had its roots in ancient historical writings, including those of Aristotle (384–322 BC) (Alvarez, 2009). Behaviourism is regarded as a reactionary movement to previous introspective and unscientific approaches to understanding psychology. Behaviourism asserts that the inner workings of consciousness are neither quantifiable nor useful in terms of a scientific approach to understanding behaviour (Watson, 1913, 1924). Schunk (2012) defines behaviourism in terms of conditioning learning theories (McInerny & McInerny, 2002), where the stimulus-response process does not account for internal processes of cognition. While theories of learning often deal with behaviour at some level, the differentiator with conditioning theories is that they are explained in terms of environmental events, or cause-and-effect stimuli. Behaviourism does not deny the existence of cognitive mechanisms but contends that such phenomena are not necessary to explain learning (Watson, 1924); moreover, one of the tenets of behaviourism with regard to learning is that these cognitive mechanisms are inaccessible to researchers and are therefore excluded as reliable evidence of learning processes (Moore, 2013).

Behaviourism assigns learning, or conditioning, to two categories. First, classical conditioning (Pavlov, 1927; David, 2007; Krause et al., 2010), which is a result of a reflexive response to a stimulus. Behaviourism posits that humans are optimally wired to the extent that stimuli will result in specific and predictable responses. Skinner (Skinner, 1938, 1951; McInerny & McInerny, 2002; McInerny, 2014) asserted that learning by all animals, a classification that included humans, occurred through the process of relative levels of behaviour reinforcement. Behavioural or operant conditioning is explained through the reinforcement of responses to stimuli and is therefore modelled on a basic feedback system (Ertmer & Newby, 1993; Bourne & Kench, 2010). The theory asserts that if a reinforcement or reward follows a response, then the same response becomes more likely to be repeated in the future. Operant conditioning has been used to train animals. For example Skinner (1948) used reinforcement techniques to train pigeons to perform actions based on the stimulus-response process (Skinner, 1951). It has been acknowledged that in some situations positive and negative reinforcement techniques may be effective (Eyre, 2007). These include treatments for disorders including autism (Lovaas & Smith, 1989), anxiety disorders (Hopko, Robertson, & Lejuez, 2006), antisocial behaviour (Termini & Golden, 2007) and irrational fears in educational environments (McLeod, 2017a). In education, behaviourism is often used by teachers who reward or punish student behaviours (Skinner, 1948; Woolfolk & Margetts, 2007).

Criticisms of behaviourism include the lack of acknowledgement of activities of the mind during learning, for example the cognitive process in which learners engage to abstract principles from facts (Krause et. al., 2010). Behaviourism also fails to explain learning where no reinforcement exists, such as the recognition of language patterns by young children (Naik, 1998); it also fails to explain shifts in behaviour due to the introduction of new information, for example, an animal being able to change or transfer behaviour it had learned through reinforcement to respond to new maze configurations (David, 2007; McInerny and McInerny, 2002).

In summary, behaviourism presents a model of learning that relies on observable behaviour which it attempts to explain in terms of universal laws (Voorhees & Bedard-Voorhees, 2017). In terms of the current study, behaviourism represents an incomplete learning model since it excludes the research that supports the role of cognitive mechanisms as a factor in learning. In other words, it does not account for mechanisms within the “black box” of cognition (Hamlyn, 1990; Grant, 1992; Ritchhart & Perkins, 2008) that have become increasingly relevant to learning through experimental studies since the late 19th century (Bartlett, 1932; de Groot, 1965; Ebbinghaus, 1885; Miller, 1956; Piaget, 1926; Sweller, 1988). Behaviourism excludes the role of subjective, affective factors, including internal motivation (De Bruin & van Merriënboer, 2017; Martin, 2016; Martin & Collie, 2018; Martin & Evans, 2020; Sweller & Paas, 2017) and learner self-regulation which have been increasingly validated in later research as being significant contributors to the learning process (Bautista, 2012; Heckhausen & Dweck, 1998; Huh & Reigeluth, 2017).

3.4 Cognitivism

From the mid-1950s, cognitivism was on the ascendancy in terms of replacing behaviourism as the dominant educational paradigm (Arponen, 2013; Chomsky, 1959; Hyman, 2012; Krause et al., 2010). Behaviourism had disregarded unobservable functions of cognition in favour of directly observable behaviours during learning, but cognitive research challenged this position and the underpinning assumptions of its key researchers including Thorndike (1898) and Watson (1913, 1924).

Cognitive research began to reveal specific but externally hidden functions of the mind, referred to as mechanisms within the “black box” (Grant, 1992; Hamlyn, 1990; Ritchhart &

Perkins, 2008) of cognition that exert an impact on learning. From early experiments by Ebbinghaus (1885) and throughout the 20th century, cognitive research gradually added deeper levels of understanding of the inner workings and mechanisms of cognition. These include aspects such as remembering and forgetting and the conditions under which these phenomena occurred, forming an increasingly coherent representation of cognitive faculties and functions related to learning.

Laying the foundation for these cognitive discoveries, the first documented example of experimental attempts to understand the inner mechanisms of memory was the set of "curve of forgetting" experiments by Ebbinghaus (1885), who used nonsense syllables to calculate the diminishing rate of memory recall over time. Ebbinghaus's research attracted criticism since he was his own experimental subject (Danziger, 1979), his experimental methods being "artificial" (Roediger, 1985, p. 5) and being based on the memorisation of nonsense syllables. However, Ebbinghaus's conclusions regarding memory function were revolutionary at the time and stimulated a new wave of research and interest into enquiry about cognition and memory through objective and scientific experimental design (Ebbinghaus, 1885; McLeod, 2008a, 2008b; Ranganath, Libby & Wong, 2012).

Ebbinghaus established broad pedagogical principles of learning. He brought to light the effect known as primacy and recency (Ebbinghaus, 1885), which suggested the phenomenon of recall was strongest by learners for items near the beginning and end of a list and weakest for items near the centre. He noted that low levels of rehearsal led to better relearning of materials; and he asserted that memorising meaningful content required as little as ten percent of the effort needed to learn nonsense materials (Wozniak, 1999). These learning principles revealed previously unacknowledged mechanisms of short-term memory and have remained in use in pedagogical practice and ongoing experimental research (Murphy, Hofacker & Mizerski, 2006; McLeod, 2008a, 2008b). Short-term memory was later termed working memory (Baddeley & Hitch, 1974; Cowan, 2010) to convey its active processing function in terms of plans that served to execute the mentally-formed, conceptual images or representations of learners into action (Paivio, 1986).

Building upon the foundation established by Ebbinghaus, Piaget (1924) advanced the understanding of memory through continuation of the investigative trajectory into memory functions. His research, which focused on the stages of development of children, provided clarity in defining long-term memory structures called schemes or schemas as the basic building blocks of intelligent behaviour (Bartlett, 1932; Piaget, 1975). Schemas have been further described as "networks of connected ideas or relationships" that facilitate the transfer of knowledge into new situations (McInerny & McInerny, 2002, p. 99). Studies regarding schemas did not only arise from psychology, but neurology as well (Head, 1920).

A key contribution of Piaget's research was a definition of schemas that advanced Kant's (1963) earlier view of schemata from a philosophical, introspective notion to an experimentally-based understanding of mental processes and structures of learning. Piaget (1924; 1936; 1972) represented the cognitive functions that underpin learning as an active processing system that progressed in alignment with children's growth through four key stages: sensorimotor (birth to ages 18–24 months); preoperational or toddlerhood (from 18 to 24 months through to early childhood–age 7); concrete operational (ages 7 to 12); and formal operational (adolescence to adulthood).

Piaget conducted research using a paradigm he termed genetic epistemology (Piaget 1936, 1952). He assigned a sense of dynamism to schemas, which he described as developing into stable mental structures through the synthesising, triarchic processes of:

a. assimilation

b. accommodation

c. equilibration.

These concepts formed the core process of his theory of genetic epistemology (Piaget, 1952, 1972; McInerny & McInerny, 2002; McInerny, 2014), with the unstable state of disequilibration providing the impetus for developing children to resolve instabilities of mental schema construction and automation (Appendix A). Genetic epistemology included the theory of cognitive constructivism (Piaget, 1968, 1970) which included key concepts of age-related intellectual stages in children and schema formation as a learning mechanism (cf. Ültanir, 2012–Constructivism).

Piaget's explanation of schemas as active and dynamically changing mechanisms (Abrahamsen & Bechtel, 2012) encapsulated both processing of information within existing mental structures, as well as the modification of schemas to accommodate new knowledge (Plass, Moreno & Brüncken, 2010, p. 1). Bransford (1985) concurred with this view of assigning equal importance to the active nature of schemas as to the formation of schemas themselves (McLeod, 2015a; Piaget, 1975). Within cognitive psychology, schemas are therefore viewed as central to the organisation of knowledge (Bartlett, 1932; de Groot, 1965; Piaget, 1972; Sweller, 1988) and within this paradigm, learning is expressed in terms of growth and changes to schemas (de Groot, 1965; Learning Theories, 2017; McLeod, 2015a, 2015b; Piaget, 1924, 1936; Sweller, 1988; Sweller, Ayres & Kalyuga, 2011).

While Piaget contributed understanding to the development of children, his research has been criticised for lacking robustness in explaining sociocultural aspects of learning, as well as the significance of the mediative roles of teachers and others in the learning process (McInerny & McInerny, 2002; McInerny, 2014). Additionally, Lourenco and Machado (1996, pp. 143–158) summarise ten criticisms of Piaget's theoretical assertions as: "underestimating the competence of children"; positing "age norms disconfirmed by the data"; characterising development "negatively"; neglecting "role of social factors in development"; "predicting developmental synchronies not corroborated by the data"; predicting and not explaining;

being “paradoxical” due to “assessing thinking through language”; ignoring “post-adolescence”; and appealing “to inappropriate models of logic”. Despite these criticisms, Piaget’s line of enquiry further established the construct of schemas as a key part of learning. His research contribution to cognition and education remain pillars of educational research to the present day.

In contrast with Piaget’s focus on cognition, Vygotsky (1896–1934), posited a socio-cultural model of learning that acknowledged the significance of cognition with greater emphasis on the social factors that play a role in the formation of learning. While Vygotsky conducted research over a similar time period as Piaget, his work was written in Russian and only became widely known after it was translated into English at a later date (Vygotsky, 1978). Vygotsky emphasised the critical role of sociocultural aspects of learning and situated learning (Vygotsky, 1930, 1978; Lave, 1988; Lave & Wenger, 1990), the significance of more knowledgeable others (MKOs) to support the advancement of learning and the underpinning theoretical construct of the zone of proximal development (ZPD) which is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p. 9). Vygotsky’s contributions are discussed in more detail in a later section of this chapter in terms of their significance to the research question.

Expanding on Piaget’s research regarding schemas, Bartlett (1932) provided clarification regarding the nature and functions of long-term memory schemas by conducting a series of memory experiments using a folkloric story called War of the Ghosts (Bartlett, 1932; see also Coulter, Michael & Poynor, 2007). Bartlett conducted an experiment where subjects recounted this story in writing successively to other subjects. Each time a subject repeated the story in writing from memory, modifications or distortions were observed to occur. Bartlett developed an explanation for this phenomenon through the theory of reconstructive memory (Bartlett, 1932; Frankish and Ramsey, 2012) which suggested that new information tended to be adjusted to fit into existing mental schemas, influenced by imagination (cf. Sweller, 2006b, p. 325) in order to create meaning (see also Wagoner, 2017).

This view aligned with Piaget's connection of schemas with meaning – the driving quest of humans (Ertmer & Newby, 2013; Zittoun & Brinkmann, 2012). Experimental findings suggested that memories were not exact copies but a reconstruction of experiences in terms of the existing schemas of learners, and Bartlett's experiments have been further validated through repeated experiments (Bergman & Roediger, 1999).

Piaget (1926) and Bartlett (1932) established principles of cognitive functioning, Piaget through his age-related human developmental theory of genetic epistemology and Bartlett through his model of schema development. By the middle of the 20th century, functions of cognition during learning were a key research direction in education. Miller (1956) published a landmark article that further stimulated cognitive research through articulating the limitations of short-term (working) memory, which was later termed working memory due to its active role in processing elements (Miller, Galanter & Pribram, 1960). A limited working memory which was prone to overloading was introduced as a critical factor in the design of learning interactions. Secondly, research into the functions of long-term memory schemas that extended the work of Bartlett (1932), the formation of expertise within specific knowledge domains (Chase and Simon, 1973a, 1973b; de Groot, 1965) and pedagogy of expert performance (Ericsson, Krampe & Tesch-Romer, 1993; Gobet, 2005) all strengthened the understanding of the relationship between the underpinning mechanisms of cognition and their impact on learning.

The growing body of cognitive research representing the cognitive revolution (Johnson, 2001) provided an explanation and representation of the function of long-term memory schemas as a critical component of learning. The research suggests that schemas encapsulate all prior knowledge of the learner within mental constructs (Hailikari, Katajavuori & Lindblom-Ylanne, 2008). Moreover, this model posits that schematic structures enable humans to have an inner mental representation of the outside world (American Educational Research Association, 2019; Galanter & Pribram, 1960; Iran-Nejad & Winsler, 2000; Johnson, 200; Miller, McLeod, 2015a, 2015b).

Schemas have been recognised as basic building blocks of knowledge and experience which are retrieved when learners are confronted with new knowledge, or when solving problems (de Groot, 1965; Sweller, 1988, 1999). Schemas have been validated in terms of their critical role in learning and are embedded in models of cognition that explain learning processes (Ranganath, Libby & Wong, 2012) and therefore inform learning design at a foundational level.

Cognitivism did not only impact pedagogy, but became a model for artificial information processing systems and the development of artificial neural networks (Gobet, 1998, 2016). The relationship between cognition and the nascent field of computing also began to develop during the 20th century, where the cognitive plans that preceded action were described as being similar to the functions programs that guide computers. Working memory began to be construed as having executive functions. Miller, Galanter and Pribram (1960, p. 65) asserted that:

> we should like to think of the memory we use for the execution of our Plans as a kind of quick-access, 'working memory.' There may be several Plans, or several parts of a single Plan, all stored in working memory at the same time. In particular, when one Plan is interrupted by the requirements of some other Plan, we must be able to remember the interrupted Plan in order to resume its execution when the opportunity arises.

Adding to the emergent understanding of the hidden functions of memory, Miller (1956) introduced an information processing analogy of learning. In addition to defining the limitations of short-term memory, Miller contributed an information processing model called TOTE (test–operate–test–exit) that became the fundamental model of information processing frameworks (Crowther-Heyck, 1999; Franklin, 2012).

Miller posited the relationship between the growing field of artificial neural networks as simulation of human cognitive processes. He stated: “It is my thesis that the physical functioning of the living individual and the operation of some of the newer communication machines are precisely parallel in their analogous attempts to control entropy through feedback” (Miller, Galanter & Pribram, 1960, p. 43). Miller’s research shed new light on the hidden mediatory functions that occurred between behaviourism’s stimulus and response process thereby surpassing behaviourism by defining greater levels of complexity associated with learning. Combined with the increased understanding of schematic formation in cognitive research (Bartlett, 1932; Gobet, 2016), these insights were influential in the early development of computer systems.

Miller’s (1956) information processing model of learning coincided with the rise of computing and computer modelling (Anderson & Gluck, 2001; Minsky, 1975), the growth of computer based instruction in education (Molnar, 1997) and artificial intelligence (Aleks, 2019; Brusilovsky, 2003; see also Heussner, 2013–Adaptive learning; Knewton, 2017), which was driven by the goal of “replicating intelligence and cognitive processes through various computational, mathematical, logical, mechanical and even biological principles and devices” (Frankish & Ramsey, 2012; McCulloch and Pitts, 1943; Minsky, 1975). Siemens (2005) and Downes (2010, 2012) developed a theory of artificial neural networks and are credited as positing the theory of connectivism.

While a gradually expanding interest in cognition had existed since Ebbinghaus, Ulric Neisser (1967) has been attributed with being the father of cognitive psychology by his development of a unified theory that researchers could use to explain their research findings (Belardinelli, 2012; Frankish & Ramsey, 2014; Newell, 1994). It was Neisser's synthesis of research that demarcated a clear line between behaviourism and cognitivism. Hyman (2012, p. 1) describes Neisser's contribution as follows:

> Neisser brought together research concerning perception, pattern recognition, attention, problem solving, and remembering. With his usual elegant prose, he emphasized both information processing and constructive processing. Neisser always described Cognitive Psychology as an assault on behaviorism. He was uncomfortable with behaviorism because he considered behaviorist assumptions wrong and because those assumptions limited what psychologists could study (Deutsch & Deutsch, 1963).

As cognitivism became increasingly established, the recognition of the role of cognition with regard to mechanisms of short-term and long-term memory exerted increasing influence on education. Schema theory had gained dominance as an educational theory further validated by the landmark research findings of de Groot (1965) in the area of chess expertise. De Groot identified prior learning in specific knowledge domains as the key to schematic development of long-term memory. Combined with Miller's (1956) position regarding the functions of short term memory and information processing model (Miller, 1960), de Groot's (1965) seminal findings regarding expertise and the perceptual processes (Gobet, 2016) added significant depth of understanding to the growing map of the learner's inner world of cognition during learning. The functions and characteristics of both short term and long-term memory systems began to emerge not only as disparate static systems but also having an active and complex interrelationship during learning (Gobet, 2013).

These findings provided deepened understanding of the mechanisms within the black box of cognition particularly with regard to education. Understanding learning in terms of its underpinning mechanisms represented a different paradigm from models that provided behavioural or "how to" guidelines, models and heuristics for informing teaching practice (Glaser, 1978–2000). In other words, cognitivism established a link between learning theory and teaching practice. Mechanisms of cognition were recognised as having operational functions that suggested hypotheses which could be tested and validated.

Building on the emergent understanding of cognitive functions, Sweller (1988, 1999) posited a unified model of cognition (de Jong, 2010) that explained learning in terms of managing the loads imposed on working memory and the impact of managing these loads on schema formation. This research direction, represented as CLT, recognised human cognition as a holistic entity with multiple functional levels and interactive mechanisms and sought to explain learning in terms of this model.

In summary, the notion of using unified models of cognition for understanding the mechanisms of intelligent behaviour was posited by Newell (1990), arguably one of the most influential thought leaders in cognitive modelling and artificial intelligence, as a necessary step in the maturation of cognitive research. Sweller's unified model of cognition and learning as represented in CLT reflected parallel thought processes with Newell's research on the use of computational modelling for understanding human cognitive architecture and the underpinning cognitive processes that are activated during learning. While Newell used a technology called SOAR (State, Operator and Result), Sweller (1988) used a computational language called PRISM which was designed to model cognitive processes (Neches, Langley & Klahr, 1986). Sweller's research findings on cognition and learning served as a catalyst for ongoing research that grew to a point of significant influence in education from the 1990s to the present day. In particular, the extension of CLT into the cognitive theory of multimedia learning (CTML) (Ayres, 2015; Clark, 2005; Mayer, 2005) became a highly influential model for informing instructional design in multimedia environments.

The next section provides an overview of constructivism, the educational paradigm that succeeded cognitivism as the dominant paradigm in mainstream education.

3.5 Constructivism

Constructivism is based on both a philosophy and psychology of learning that operates from the position that learners construct their own knowledge, understanding and inner representation of the external world and environment (Bruner, 1960; Dewey, 1938; Glasersfeld, 1989, 1995; Perkins, 1999; Thompson, 2000; Vogel-Walcutt, et al., 2010; Vygotsky, 1978).

From an educational perspective, Piaget (1967) is attributed with introducing the notion of a constructivist epistemology. Underpinning the contemporary emergence of constructivism, Bachelard (1884/1967) proposed the view that, "For a scientific mind, all knowledge is an answer to a question. If there has been no question, there can be no scientific knowledge. Nothing goes without saying. Nothing is given. Everything is constructed" (Bachelard, 1934, p. 17).

Constructivism is by no means a new learning paradigm. Mahoney and Granvold (2005) posit that it has its philosophical roots in teachings of the ancient Greek philosophers Heraclitus, Protagoras, and Aristotle as well as Hegel (1807/1949), Kant (1781/1946) and Vico (1725/1968). Doolittle and Camp (1999) assert that constructivism represents more of a spectrum or continuum of ideas rather than a singular unified theoretical notion or position. It has been defined in terms of three key strands: a. cognitive b. social and c. radical (Cardellini, 2006, Glasersfeld, 1995, 2000, 2007, 2010, 2014). The research field of constructivism is therefore vast and varied, with many fragmented schools of thought representing different relativistic research methods and foci; Philips (1995, p. 7; cf. Glasersfeld, 2010, 2014) refers to "constructivisms" to reflect the plurality within the constructivist framework, which also concurs with the position of other researchers (Doolittle & Camp, 1999; Tieszen, 2000;

Perkins, 2006). The divergent nature of constructivism as represented by the notion of many constructivisms (Doolittle & Camp, 1999) therefore represents a key difference compared with cognitivism, which sought convergence towards a unified model of cognition that could explain the underpinning of mechanisms of learning and memory functions at a detailed level (Newell, 1990; Sweller, 1988).

Due to this approach, the constructivist view remains open to varying methodologies in social science research. However, it is noted that the diverse range of definitions of constructivism as well as its absence of coherent model of cognitive mechanisms underpinning learning weakens its pedagogical application as a cogent system for defining learning designs and therefore its suitability for use as an objective standard for validating and evaluating learning design (cf. Glasersfeld, 2000). The notion of everything being constructed (Bachelard, 1934) does not readily specify a unified set of quantifiable evidence-based strategies or effects that take into account methodological, theoretical or pedagogical considerations that arise in different learning environments (Alanazi, 2016).

This view is supported by key researchers (Clark, Kirschner & Sweller, 2012; Ertmer & Newby, 1993, 2013; Hardy & Taylor, 1997; Kirschner, Sweller & Clark, 2006; Perkins, 1999, 2006), who affirm constructivism as an interpretivist ontological paradigm that de-emphasises the notion that reality is objectively verifiable, or that realism exists externally to individual perceptions (Glasersfeld, 2007). Hendry, Frommer and Walker (1999, p. 1) summarise this view succinctly by asserting that “knowledge cannot exist outside our minds. Knowledge cannot be given from one mind to another”. The implication of this view is that it becomes extremely difficult to establish any kind of objectivity with regard to generalisable learning strategies, therefore creating a problem with establishing an objectively derived evidence-based standard that lends itself to use as the basis of this study.

At its core, constructivism posits an observable, collaborative approach to learning that frames the learner as an active participant in constructing knowledge as opposed to a passive recipient of information (Philips, 1995). Learning is therefore conceptualised as a process where the creation of new knowledge through experiments and solving real world problems is facilitated. The role of the teacher is to guide this process through understanding the prior knowledge and preconceptions of the learner, then facilitate the building of new knowledge (Ciot, 2009; Ulatnir, 2012).

Some approaches associated with constructivism have emerged to demonstrate the process by which knowledge may be constructed. For example, constructionism (Papert & Harel, 1991) posits the necessity for learners to create concrete artefacts to express the outcomes of internally constructed learning (Ackermann, 2004). Additionally problem-based learning (PBL) (Kemp, 2011) is an example of an approach arising from constructivist pedagogical practice. PBL posits the view that learning occurs by exposing learners to multiple problems and through a combination of discovery learning and guidance, learners construct their understanding of the subject. Some researchers (Hmelo-Silver & Barrows, 2006) note that this kind of learning may be very effective in mathematics classes because students try to solve the problems in many different ways, thus stimulating their minds. It is similarly widely used in medical education (Chang, 2016; Hmelo-Silver & Barrow, 2006).

However, the specific how-to strategies for achieving the end goal of successful knowledge construction tends to lack clarity (Kirschner, Sweller & Clark, 2006). Consequently, while constructivism posits a learner-centred view of learning processes and an explanation of how learners build internal constructs, it does not provide a standard pedagogical prescription for facilitating this process (Glasersfeld, 1995; Perkins, 1999; Philips, 1995). Moreover, constructivism does not provide a theoretical framework that acknowledges the underpinning mechanisms of cognition, for example, identifying poorly or erroneously constructed schemas. In practice, the constructivist view of education is underpinned by search-based approaches to learning such as experiential learning, problem solving, discovery learning, exploration and questioning, as well as repeated reflection on those experiences (Ciot, 2009; Krause et al., 2010, pp. 188–199). However, these search-based approaches have a critical weakness: they facilitate a default means–ends analysis cognitive process that has been experimentally validated as a weak learning strategy for novice learners who have not yet formed and automated a critical mass of schemas in a particular knowledge domain (Newell & Simon, 1959, 1961; Sweller, 1988, 2006a).

Constructivism is further exposed by not having a unified theory of cognition to explain learning mechanisms that underpin learning processes. For example, constructivism does not engage the discursive language of cognitivism such as schemas, the limitations of working memory and functions of long-term memory to explain learning processes; neither does it assume a predictive model of learning based on a cogent model of human cognition. Rather, it defines learning in terms of guiding pedagogies that are enacted within a sociocultural environment such as the “spiral curriculum” (Bruner, 1960, pp. 52–54); frameworks such as Bloom’s taxonomy (1956); anticipatory sets (Hunter, 2004) that engage the learner through activating prior knowledge before proceeding with new learning; or the teacher changing roles “from the sage on the stage to the guide on the side” (King, 1993, p. 30).

Mayer (2004) affirms the value of constructivist learning as an active learner-centric process (Bain, 1999; Bedard-Voorhees, 2017) but questions the validity of constructivist teaching, which he refers to as “the constructivist teaching fallacy” (Mayer, 2004, p. 15). The fallacy lies in the approach to teaching that assumes learners will discover and construct their own learning without explicit direct guidance from a more knowledgeable other (MKO) (Vygotsky, 1978). It is the lack of explicit and direct teaching of domain-specific knowledge to novices that differentiates constructivism from cognitivism. Kemp (2011, p. 47) reinforced the assertion that constructivism was more descriptive of learning than teaching, stating that:

> It is important to remember that constructivism is a theory that describes learning, not a method of teaching. Although a teacher may make decisions, and may base actions on beliefs that are consistent with Constructivism, as a theory, Constructivism does not suggest how an individual should learn but offers an account of how learners construct knowledge. What constructivist principles do not do, regardless of the form, is automatically provide a prescription for principles of teaching.

Besides issues of methodology, additional criticisms levelled at constructivist approaches include a departure from direct teaching methodologies (Kirschner, Sweller & Clark, 2006), being inefficient (Furtak, Seidel, Iverson & Briggs, 2009), and lacking a single, unified theoretical framework (Glasersfeld, 2000; Perkins, 1999). Additionally, constructivism does not include a validated pedagogy of self-efficacy or heutagogy (Hase & Kenyon, 2001; Narayan, Herrington & Cochrane, 2019) that supports the development of learner capability as learning is constructed.

Constructivism has some tacit assumptions that also contribute to weakening its efficacy as an objective evaluation standard; for example, it assumes that learners have the self-reflective and self-regulatory capability to construct valid representations of external knowledge (Bachelard, 1934; Franck, Land & Schack, 2013; Paivio, 1986; Vrieling, Stijnen & Bastiaens, 2018). Since constructivism varies in approaches between norm-referenced and criterion referenced paradigms (Cato, 2001), as opposed to being strictly criterion-referenced (Bloom, 1984; Mager, 1975, 1988; Mager & Pipe, 1984), teachers have no universally validated standards for determining the quality of the cognitively constructed representations of learners. This approach is encapsulated in the use of norm referenced assessment which is implemented "to classify students [and] … to highlight achievement differences between and among students to produce a dependable rank order of students across a continuum of achievement from high achievers to low achievers" (Bond, 1996, p. 1). In contrast, criterion referenced assessment, typical of more cognitively-designed approaches, defines specific outcomes and assumes a flexible time paradigm in order for learners to achieve set outcomes (Bloom 1968, 1984).

Some researchers have observed that in practice constructivism does not occur in its pure form (Cey, 2001) where learners are expected to construct their own knowledge without some type of guidance, support and direct transmission of knowledge from more knowledgeable others (cf. Crawford, 1996–Vygotskian approaches; Vygotsky, 1978), or expert others (cf. Kirschner, Sweller & Clark, 2006–Guided instruction). Moreover, the widespread use of technological systems in education automatically introduces direct and explicit teaching pedagogies more associated with cognitivism than with constructivism. However, as constructivism does not prescribe a pedagogical methodology, this form of direct teaching is more likely to be driven by a hybrid model of teaching or by technology rather than by a specific constructivist pedagogy.

In following the principle of learners constructing their own knowledge, constructivism therefore tends towards some theoretical weaknesses, namely the lack of:

1. being informed by a model that recognises the underpinning mechanisms and functions of cognition during learning
2. direct and explicit teaching of content within knowledge domains (de Groot, 1965)
3. continued, deliberate practice (Ericsson, Krampe & Tesch-Romer, 1993) of core content knowledge to the point of mastery by learners (Bloom, 1968, 1984; Kirschner, Sweller & Clark, 2006; Sweller, 1999)
4. targeting the evaluation and strengthening of skills of learners who may have low heutagogical capability (Hase & Kenyon, 2001) or inadequate mental representations of domain knowledge

The omission of explicit teaching strategies aligned with human cognitive architecture

(Sweller, 1999; Klahr & Nigham, 2004) has implications for education and may run counter to the goal of supporting learners towards attaining increasingly higher levels of expertise in specific knowledge domains (de Groot, 1965; Chase & Simon 1973). Sweller (1988, 1999) reiterates de Groot's (1965) finding that expertise is contained in domain-specific schemas, by stating (1999, p. 155):

> Direct instruction in which students are presented both relevant, widely accepted factual material along with the various arguments associated with controversial issues could be expected to facilitate learning. As far as I am aware, there is no body of literature demonstrating negative effects with direct instruction.

The increasing call for evidence-based teaching and learning (Masters, 2018) requires all learning strategies, and particularly constructivist approaches, to be rationalised through "rigorous research and testing" (Glasersfeld, 2009, p. 6). Without an evidence-based framework for determining the relative effectiveness of different pedagogies, constructivism may lack the internal validity to advance and improve continuously from a theoretical perspective (cf. Bain & Drengenberg, 2016). Sweller, Ayres and Kalyuga (2011, p. 12) summarised this conclusion succinctly:

> The reasons why constructivist teaching is assumed by many to be superior are not entirely clear because the reasons tend neither to be based on any obvious cognitive architecture nor on a body of data. Nevertheless, it seems possible to discern two categories of explanation. The first category assumes that withholding information from learners will, paradoxically, result in their acquiring that information better. The act of discovering information improves the quality of information according to this view. Discovered knowledge should be qualitatively better than directly taught knowledge (Bruner, 1960). If this view was correct, then knowledge acquired during problem solving should be superior to knowledge acquired while studying worked examples. Evidence for this proposition is entirely absent. In fact, rather than providing support, the evidence is contrary to a discovery

> learning/constructivist position. Klahr and Nigam (2004) found no difference between the quality of knowledge of science learners who discovered a science principle as opposed to those who were explicitly instructed in the principle. The only difference was that those who were required to use a discovery approach took longer with fewer students learning the principle. Furthermore, evidence based on the worked example effect (Sweller & Cooper, 1985) is quite the reverse of what we should expect based on a constructivist, discovery learning viewpoint. The worked example effect occurs when learners learn more and are better at solving subsequent problems after studying worked examples rather than solving problems.

Thomson (2000, p. 415) observed that "Constructivism, by itself, cannot sanction any particular pedagogical approach". Specifically, it lacks a process for determining the internal validity of learning interventions i.e. the appropriateness of a measure for the specific inferences or decisions that result from the scores generated by the measure (Griffin & Nix, 1991; Kelly, 1927; McInerny & McInerny, 2002, pp. 350–351; McInerny, 2014). It is this factor that makes constructivism in its unmodified form unsuitable as the basis for a learning design evaluation standard.

3.6 Connectivism

Connectivism is an emerging paradigm that proposes the incorporation of digital technologies into a theoretical learning framework. Siemens (2005) and Downes (2010) advanced a theory learning for the digital age that they termed connectivism. Connectivism has been described (Downes, 2010, 2012, p. 9) as "the thesis that knowledge is distributed across a network of connections, and therefore that learning consists of the ability to construct and traverse those networks".

Kop (2008, p. 2) describes connectivism as "a theoretical framework for understanding learning. In connectivism, the starting point for learning occurs when knowledge is actuated through the process of a learner connecting to and feeding information into a learning community".

Connectivism is based on a technological paradigm that takes technology into account as a medium of learning, as well as the learner's capability of navigating technology for learning purposes. Duke, Harper and Johnson (2013, p. 4) regard connectivism as worthy of consideration within the discourse of learning since it has "forced educators to look at what is being done in digital education and rethink, debate and philosophize over how each part fits". Siemens (2005, p. 1) notes that connectivism:

> advances a theory of learning that is consistent with the needs of the twenty-first century and his theory considers trends in learning, the use of technology and networks, and the diminishing half-life of knowledge. It combines relevant elements of many learning theories, social structures, and technology to create a powerful theoretical construct for learning in the digital age.

Some criticisms of connectivism have arisen, specifically, the question as to whether it is a learning theory or an instructional theory. Duke, Harper and Johnson (2013) observe that while connectivism is emergent and yet to be established as a theory in its own right, it forms a useful node around which other ideas may be organised. In addition, Kop and Hill (2008) have questioned whether connectivism should be regarded as a separate learning theory in its own right. Closely associated with connectivism is the emerging multidisciplinary theoretical framework of connectionism (Papert & Harel, 1991) which draws on research regarding the underpinning mechanisms of cognition, but also draws on principles of neural networks and information processing models established in the research arising from cognitive science (Sun, 1996). This model represents a recognition of the roots of learning in cognition as well as an anticipatory model of increased technological connections to support learning.

In summary, connectivism is relevant to this study as an emergent paradigm of learning in a technologically connected world. However, it requires additional research to establish a specific pedagogy that has been empirically validated. The usefulness of connectivism to the current study is due to its use of technological architectures for managing, facilitating and evaluating learning. In particular, connectivism aligns with the positioning of the current study within the research domain of information systems (IS) (Bertalanffy, 1968; Branson et al., 1976; Brusilovsky, 2003; Carlsson, 2004, 2010; Jantsch, 1973; Hevner, 2007; Wynn & Williams, 2012) due to the goal of the study to design and develop a new software application in the form of a system for supporting the design–teaching–learning–evaluation cycle.

3.7 Summary

This chapter providing an overview and discussion of four key paradigms of learning that arose during the 20th century. These paradigms represent the broader context of the study in which cognitivism emerges as a rational selection in which to position an evidence-based evaluation framework. Behaviourism characterised learning in terms of stimulus reaction responses thereby excluding the structure and functions of cognition from learning theory. Behaviourism was superseded by cognitivism which investigated the inner mechanisms of learning through an information-processing model. It contributed foundational principles for informing learning design that are ecologically valid i.e. generalisable beyond local contexts, for example by taking cognisance of the specific strengths and weaknesses of memory systems during learning. These principles include: the inherent limitations of working memory; the strengths and capabilities of long-term memory; and the significance of the learner’s prior knowledge as expressed through schema formation and activation. Cognitivism was noted as contributing an integrated model of human cognitive architecture that factored cognitive mechanisms into the design of effective learning, arising from over one hundred years of experimental research. The cognitivist model of learning was therefore identified as representing a significant contribution to the quest for evidence-based practices to inform the evaluation of the quality of learning design in this study, despite perceived weaknesses relating to a lack of social context within this learning model.

Constructivism, which surpassed cognitivism as the dominant educational paradigm, was identified as a paradigm that represented a wide range of views of reality, operating on the principle that learning was a constructed reality within the mind of the individual learner. Constructivism was noted as being non-prescriptive in terms of generalisable teaching strategies, favouring search and discovery methodologies. A significant weakness with constructivism with regard to its usefulness in this research was its lack of evidence-based validation as a practice e.g. through the use RCTs within a framework of cognition, therefore making it unsuitable for informing the design of an evidence-based evaluation instrument, since, “Any instructional procedure that ignores the structures that constitute human cognitive architecture is not likely to be effective” (Kirschner, Sweller & Clark, 2006, p. 76). For this reason, a cognitively-derived model that factors in the structures and functions of human cognitive architecture into learning presents a suitable theoretical framework for the purposes of this study.

Connectivism was observed as a developing theory of learning that takes technological factors including the World Wide Web into consideration for connection and collaboration between learners. However, it was also noted that the precise nature of the theory was still nascent and therefore unsuitable as a complete framework for a learning design evaluation standard.

Having provided an outline of the four key educational paradigms of the 20th century, as well as highlighting cognitivist pedagogies as a suitable framework for the purposes of this study, the next chapter investigates specific approaches to learning that arose during this era.

Chapter 4 – Literature Review: Part C

Overview of Historical Research Contributing to Cognitive Load Theory

4.1 Introduction

To this point in the study, Chapter 2 derived a standard for evaluating the quality of educational research. It also identified and classified approaches to the design–teaching–learning–evaluation cycle in a proposed taxonomy of 19 categories. Chapter 3 provided an overview of the four key educational paradigms that formed the backdrop to these approaches during the 20th century. The result of this analysis was the confirmation of cognitive research, and particularly CLT as an approach to learning that presents a strong case for use as an evidence-based framework for evaluating learning design.

Having identified CLT for use as an evidence-based framework, this chapter presents a chronological overview of historical research contributing to the CLT model of human cognitive architecture. By defining the origins and contributions of early cognitive research to CLT, the model it proposes is validated in terms of the quest for an evidence-based body of knowledge for informing the design of CLEMS in this study. As a secondary point in this argument, de Jong's (2010) critique is addressed that CLT does not acknowledge its historical grounding through its links to prior research.

4.2 Historical roots of cognitive load theory

The aim of this chapter is to focus on the key researchers who contributed to the growing field of cognition during the nineteenth and twentieth centuries and who demonstrated "the possibility of enlarging our knowledge of memory" (Green, n.d.). This chapter identifies the specific findings of researchers who enlarged the knowledge base of human cognitive architecture, findings that were later unified into the complete model of human cognitive architecture postulated by CLT (Newell, 1990; Sweller, 1988; Sweller, Ayres & Kalyuga, 2011).

4.2.1 Ebbinghaus (1850–1909): The "forgetting curve"

Hermann Ebbinghaus (Ebbinghaus, 1885) was an early pioneer of the scientific study of cognition, with the aim of "penetrating more deeply into memory processes" (Roediger, 1985; Postman, 1968). Ebbinghaus's specific focus was the study of memory, where memory is broadly defined to include learning processes, retention of information, the linking and association of memory and reproducing learned information (Ebbinghaus, 1885; Postman, 1968). His work was a catalyst for a large amount of cognitive research and he may therefore justifiably be called a pioneer of the contemporary school of cognitive psychology.

Ebbinghaus conducted experiments that gave rise to findings about the forgetting curve, in which he demonstrated two key properties of memory. First, he defined the function of memory retention in relation to time (Ebbinghaus, 1885); and secondly, he clarified the spacing, or spaced learning effect, which consists of spaced repetition during learning (Ebbinghaus, 1885) that demonstrated greater learning gains through spacing learning over time as opposed to long, intensive learning episodes (Woodworth, 1909).

Ebbinghaus himself was the only subject of his experiments, which later became a valid criticism of his work and findings (Murre & Dros, 2015). To study "forgetting", he used pseudo-words, or nonsense syllables of three letters from which culturally associated meaning had been removed. Through his experiments he came to several conclusions regarding the "hidden" mechanisms of memory, or what later became known as the black box of cognition (Hamlyn, 1990; Grant, 1992). One of these findings was that meaning is imposed on meaningless symbols in order to support memory (Ebbinghaus, 1886; Green, n.d.). This associative principle is used in memory systems such as the link system (Murdock, 1985).

Ebbinghaus's experiments contributed greater understanding to memory and supported the conclusion that recall occurred according to three patterns: first, by exertion of the will; secondly, by involuntary recall that is stimulated by other associated factors; thirdly, by "the effects of accumulated experience" (Ebbinghaus,1885, p. 3; Murdock, 1985).

According to Postman (1968), Ebbinghaus represented a ground shift in four key areas of contemporary knowledge: first, he separated philosophy and psychology, thereby placing psychology on a footing of natural science; he liberated studies of the mind from information regarding functions of the mind to endeavouring to attain an understanding of the actual workings or mechanisms of the mind via experimental means and methods. He was creative and practised methodological eclecticism by adopting experimental processes from other disciplines to use for the study of the mind; finally, he reconciled pure and applied psychology, where he elevated problem and method over the context in which the solution is pursued (Woodworth, 1909). Above all, Ebbinghaus was an experimentalist and an innovator bent on substituting controlled measurement for speculation. His research initiated experimental studies that were later continued by Piaget (1926).

Ebbinghaus (1885) laid the foundation for the experimental study of the hidden workings of the mind (Hamlyn, 1990; Grant, 1992; Green, n.d.) using evidence-based experimental methods. In his time, Ebbinghaus was viewed as being contrary to current tradition by wresting psychology from philosophy and introducing much sharper methodological instruments to seek answers regarding the functions of the mind (Thorne & Henley, 2005). Ebbinghaus's focus on the limitations of memory (Wozniak, 1999) can therefore be seen as the earliest historical experimental influence on CLT, even though the relevance of his work has been eclipsed by the successive behavioural and constructivist eras of education.

Ebbinghaus was not the only researcher of his era who investigated the functions of memory. His contemporary, William James (1907, 1909), who has been attributed as the father of pragmatism as an ontological paradigm (Carlsen & Mantere, 2007; Hammond, 2013), also investigated the structure and functions of memory with regard to learning. James distinguished between primary and secondary memory, where primary memory remained active and secondary memory faded (but could be recovered). This observation caused James to conclude that limits should be placed on the volume of information introduced in primary memory since it was inherently weak. With the work of both Ebbinghaus and James, the turn of the twentieth century was characterised by stirrings of interest in a deeper understanding of the hidden mechanisms and workings of the mind during learning.

4.2.2 Jean Piaget (1896–1980): Schemas (mental models), adaptation and stages of child development

Jean Piaget, the Swiss psychologist, was the first psychologist to conduct a systematic study of the cognitive development of children (Piaget, 1926, 1972, 1975). He referred to himself as a genetic epistemologist (Kitchener, 1980), linking a theory of knowledge to genetics and stages of child development. Piaget's genetic epistemology varied from philosophical epistemology by being empirical and testable (Piaget, 1972) and thus Piaget's work continued on the same investigative trajectory as the research conducted by Ebbinghaus.

Piaget's experimental work advanced the understanding of the distinct stages of intellectual development of children beyond the contemporary view of children as adults in a miniature form (McLeod, 2015a; Piaget, 1924, 1932, 1970, 1972). In his theory of cognitive development, Piaget delineated the four disparate but progressive stages of intellectual growth of children, related to different age ranges (Krause, Bochner, Duchesne & McMaugh, 2010, p. 53; Piaget, 1970, 1972, 1975).

Piaget (1926, 1970, 1972) also defined the specific processes for transitioning from one stage of intellectual growth to the next through processes of modifications to memory schemas. These processes were termed assimilation (where an existing schema is used to reference a new item i.e. situation, idea or object), accommodation (where an existing schema does not reference a new item and needs to be modified to accommodate new perceptions and knowledge), and equilibration (the force that drives learning to the next stage of development by stabilising the new knowledge as a part of existing schemas) (Piaget, 1970, 1972, 1975; McLeod, 2015a). Piaget also used the term disequilibration to describe the uncomfortable stage when new knowledge does not fit into existing schemas at the assimilation stage (Piaget, 1970, 1972). Equilibration was described as the condition of stability sought by the learner to bring about the necessary balancing adjustment to the mental schema when new information is introduced. This growth process repeats with each new learning situation and describes the dynamic nature of Piaget's model of intellectual growth.

Piaget's work stimulated research into the field of developmental psychology as a discipline in its own right (Piaget, 1926, 1970, 1972). In addition, he related his research to pedagogical philosophies and strategies, thereby strengthening the link between cognitive psychology and education. In terms of theoretical contributions, Piaget's work was rooted in cognitive theory but he was also a pioneer of constructivism, suggesting that learners construct their own knowledge through actively participating in the educational process based on interactions between intellectual ideas and practical experiences (Krause, Bochner, Duchesne & McMaugh, 2010, p. 61; Mai, 1974; Piaget, 1936, 1972, 1975). This view aligns with those of Dewey (1938), Bruner (1960) and Vygotsky (1930, 1978), who together with Piaget represent key researchers in the emergence of constructivism, a dominant educational paradigm during the 20th century.

While Piaget's focus was on the intellectual development of children, his purpose was to inform and transform education (Piaget, 1953, 1970, 1972). McLeod (2015a, p. 1) notes that Piaget "disagreed with the idea that intelligence was a fixed trait, and regarded cognitive development as a process which occurs due to biological maturation and interaction with the environment”.

Piaget advanced a type of creative and progressive education stating that, “The principle goal of education in the schools should be creating men and women who are capable of doing new things, not simply repeating what other generations have done” (Jervis & Tobier, 1988, p. 1). He challenged contemporary norms and advanced educational ideals that aligned with the natural developmental stages of intellectual maturity (Piaget, 1926).

Criticisms of Piaget’s research have been summarised by Lourenco and Machado (1996) and other researchers as: focusing on the intellectual development of children and not adults (Piaget,1926; Crossland, 2017); having limited numbers of subjects for his experiments, therefore generating research with limited generalisability; problems with linking intellectual growth to biological growth – implying that stages of growth are not guaranteed for all learners (Weiten,1992); failure to consider the potential effects of social and cultural influences on cognitive development (Nicolopoulos, 1993; Vygotsky, 1978); possible bias in recording experimental results due to conducting research using his own three children as subjects (Hopkins, 2011); possible underestimation of children’s cognitive abilities (Lourenco & Machado, 1996); lack of tangible evidence for schema theory since schemas cannot be objectively measured (Thorndyke & Yekovich, 1980); and his belief that thought preceded language (Krause, Bochner, Duchesne & McMaugh, 2010; McLeod, 2015a; McLeod, 2018).

Piaget (1952, 1967, 1972, 1975) left an immense research legacy in developmental psychology as well as education, reflecting several distinctive themes related to the development of children. His elaboration of schema theory and particularly his explanations of the inner processes of learning created the theoretical foundation on which CLT was later developed. For example, the information store principle in CLT aligns with Piaget’s formation of schematic structures in memory. In addition the novice working memory and the narrow limits of change principle in CLT aligns with Piaget’s processes of assimilation, accommodation and equilibration (see Chapter 5).

While Piaget advanced the notion that thought preceded language and developed schema theory, Vygotsky explained cognitive processes by suggesting that language preceded thought, as expressed in his social constructivist model which is outlined in the following section.

4.2.3 Lev Vygotsky (1896–1934): Social learning precedes development

Vygotsky was a Russian psychologist who advanced a sociocultural theory of cognitive development, which stated that language in social contexts preceded thought (Vygotsky, 1930; Nicolopoulos, 1993). This contrasted with Piaget's view that thought preceded language (Piaget, 1926). In addition, Vygotsky's work represented a shift away from schema theory to a priority on sociocultural theory (McVee, Dunsmore & Gavalek, 2005).

Vygotsky delineated three key themes in his social development theory (David, 2014). The first is social interaction where he stated that, "Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people ("interpsychological") and then inside the child ("intrapsychological") (Vygotsky, 1978, p. 57).

The second theme is the more knowledgeable other (MKO), where the MKO can refer to any other person who has attained a higher level of knowledge, skill, ability or capability than the learner with respect to a specific task, process, concept, or application of knowledge. The MKO is normally thought of as being a teacher, coach, or older adult, but the MKO may also be a peer of the learner, a younger person with higher levels of knowledge, or even computers from which knowledge may be accessed or elicited (Keengwe & Onchwari, 2016, p. 234; Mai, 2014; Siemens, 2005, 2010; Siemens, Dawson & Lynch, 2013; Tuovinen, 2000). The third theme, the zone of proximal development (ZPD) which is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1930, p. 9). Understanding this difference provides a key for educators and other experts in assisting learners to advance towards mastery and expertise in their learning (Rasku-Puttonen, Etelapelto, Arvaja & Hakkinen, 2003; Warwick & Maloch, 2003). ZPD may share commonalities with the progression of learners from liminal spaces or states, defined as instability, lack of conceptual clarity and possible anxiety (Meyer & Land, 2006) to a position of clarity in understanding a particular concept. In order to traverse the unknown ZPD or liminal state, Vygotsky's notion of the more knowledgeable other (MKO) suggests a scaffolded, supported process for guiding learners from current, lower levels of capability to new, higher levels of understanding beyond the familiar (cf. Tuovinen, 1999; Warwick & Maloch, 2003; Wittrock, 1966). Vygotsky's theory promotes learning contexts in which students play an active role (Vygotsky, 1978). An example that illustrates this is reciprocal teaching, which integrates student-directed learning with teacher intervention (Palinscar & Brown, 1984). Roles of the teacher and student are therefore shifted, where teachers collaborate with their students to help facilitate the construction of meaning. In this model, learning becomes a reciprocal experience for the students and teacher, where teachers may facilitate increased levels of sophistication of interactions with texts (Krause, Bochner, Duchesne & McMaugh, 2010; Sporer, Brunstein & Kieschke, 2009).

Shabani, Khatib and Ebadi (2010) observed that the pedagogical aspects of scaffolding are not always clear in terms of specific interventions or mediation. The scaffolding construct therefore requires consideration in terms of the specific needs of individual learners with regard to prior knowledge (Sweller, 1988) and the intended goal of learning. The ZPD aligns with the model of human cognitive architecture posited by CLT through two principles:

1. the novice working memory and the narrow limits of change principle (David, 2017; Sweller, Ayers & Kalyuga, 2011, p. 40)

2. the borrowing and reorganising principle, where information is borrowed or obtained from other minds or sources.

Some implications of these principles are:

a. that enough time should be allocated for schema formation and automation

b. the specific levels of the learner's prior knowledge and capability require careful consideration in advancing learners to new knowledge levels in supported learning environments

5. that instructional strategies are used that align with the structures (limited capacity for change) and functions (borrowing knowledge and reorganising it into schemas) of human cognitive architecture.

The above three pedagogical principles echo Bartlett's (1932) key research that illuminated the understanding of long-term memory schemas as the mental structures that function as the repositories of learned knowledge.

4.2.4 Frederic Bartlett (1886–1969): Advancing schema theory

While Piaget expressed learning in terms of growth in schemata, the concept of schemata was brought to prominence in psychology and education through the work of the British psychologist Sir Frederic Bartlett (1932). In carrying out a series of studies on the written recall of Native American folktales with experimental subjects, Bartlett noticed that many of the recollections were not accurate but involved the replacement of unfamiliar information with something more familiar (Bergman & Roediger, 1999).

The recall of information included many inferences that went beyond the information given in the original text. To account for these findings, Bartlett proposed that people have schemata or unconscious mental structures or representations that denote an individual's generic knowledge about the world (Gilchrist & Cowan, 2010). It is through schemata that existing knowledge schemas influence new information (Bartlett, 1932, pp. 300–304). For example, one of Bartlett's participants read the phrase: "something black came out of his mouth" in the story titled War of the Ghosts and later recalled it as "he foamed at the mouth" (Bartlett, 1932, p. 65–70). This finding could be accounted for by assuming that the input

information was not consistent with any schema held by the participant and so the original information was reconstructed in a form that was consistent with one already existing in a schema of the learner.

Bartlett concluded two key findings from these experiments. First, a levelling or flattening of aspects of the story that were new to participants occurred, resulting in less emphasis or disappearance of those aspects from the repeating of the story. Second, there was a sharpening of the aspects of the story that existed in the long-term memory of participants. "Thus, participants did not remember the passage as it was presented, but rather, remembered a construction that consisted of a combination of the passage and previous information held in long-term memory" (State University, 2018).

Bartlett's research deepened the contemporary understanding of schema construction and automation and its role in learning (Iran-Nehjad & Winsler, 2000), although Barlett himself (1932, p. 3) used but disliked the term schema, preferring the term *organised setting*. The schema construct provided educators and psychologists with an approach to conceptualising inner cognitive processes and knowledge representation during learning (cf. Sweller, 1988). Specifically, it provided insight into the role that existing knowledge plays as learners acquire new knowledge (Bartlett, 1932). Later, this work was built upon by other schema theorists: de

Groot (1965) who clarified the nature of expert knowledge and use; Atkinson & Shiffrin (1968) who developed the "multistore" model of memory; and Chase & Simon (1973a) who replicated de Groot's findings in repeated experiments.

Bartlett's research findings were not only pivotal and foundational for later research into schemas, but also influential in the advancement of computer science and artificial intelligence through the work of Marvin Minsky (1975). Minsky developed frame theory and adopted the model of human schematic structures suggested by Bartlett, transposing it to the architecture of artificial intelligence and expert systems. Minsky replicated the role and functions of schemata and applied this understanding to machine learning, thereby validating these discoveries by modelling them within the discipline of computer science. Minsky brought clarity to two notions that were significant in human learning. The first was related to expertise. Minsky (1975, p. 257) stated:

> The key component of an expert system is the knowledge it contains. A common misconception is that artificial intelligence, in general, and expert systems in particular are magical approaches for solving problems: If a problem cannot be solved using conventional approaches, then just add a pinch of AI and a dash of expert systems and all the difficulties will disappear! This is far from the truth. What is offered by these fields is a set of tools that can aid in the solution of some problems. These tools, however, are not quick fixes or sorcery. For these tools to be effective they must have knowledge about the application.

The second point relevant to learning is that in expert systems there is a clear delineation between the knowledge and its use. Minsky conjectured that the knowledge base required a separate functioning "inference engine" that "embodies knowledge about how to use the information when solving the problem" (Minsky, 1975, p. 258). In learning theory, this became known as an "executive function" of working memory (Baddeley, 1996) implying that memory was not the static short-term model propounded by Miller (1956) but a dynamically active system that worked as represented in Sweller's (2010) borrowing and reorganising principle (Sweller, Ayres & Kalyuga, 2011). Sweller provides a different explanation for executive memory function, attributing it to existing knowledge schemas as opposed to a separate higher-level executive process. Sweller, Kalyuga & Ayres (2011, p. 35) state:

> The cognitive architecture used by cognitive load theory does not postulate nor need an independent central executive (Sweller, 2003). A central executive is a structure that organises and controls cognitive processes. During problem solving, knowledge indicates which moves should be made and when and how they should be made. In effect, knowledge held in long-term memory acts as a substitute for an independent central executive. In the absence of knowledge, a random generate and test procedure is used instead.

These contrasting interpretations of conjectured executive functions of memory systems demonstrate the active quest by researchers to understand cognitive architecture in greater depth. Bartlett's (1932) work laid the foundation not only for future research into schema theory related to human learning, but provided a theoretical model for advancing research into artificial intelligence and machine learning (Feltovich, Prietula & Ericsson, 2006; Gobet, 2000, 2005; Gobet & Simon, 1996; Miller, Galanter & Pribram, 1960; Minsky, 1975; Schank & Abelson, 1975).

4.2.5 Richard Anderson (1934–): Advancing schema theory

During the 1970s schema theory advanced through the linguistics research of Richard Anderson. He asserted that the research of Bartlett (1932) and other advocates of schema theory (Ausubel, 1960, 1963, 1978; Ausubel, Novak & Hanesian, 1978) was vague and inconclusive despite seeking to explain this theoretical construct with greater clarity (Anderson, Spiro & Anderson, 1978).

Anderson adopted Bartlett's term schemata to refer to the mental structures in which general knowledge is incorporated (Anderson, Spiro & Anderson, 1978) and also referenced Minsky's frames (1975) and Schank and Abelson's scripts (1975) which have been used to explain knowledge formation within cognitive structures. Anderson concurred with the view that schemas were "slots or placeholders that can be instantiated with certain particular cases" (Anderson, Pichert, Goetz, Schallert, Stevens & Trollip, 1976, p. 3).

Anderson developed the concept of ideational scaffolding (Anderson, Spiro & Anderson, 1978, p. 3) that provided greater definition to schema theory expressed as, "A schema will contain slots into which some of the specific information described in a message will fit" (van der Veer, Tauber, Green & Gorny, 1984, p. 211). His conclusion was that the schemata a person already possessed are a principal determiner of what can be learned from text. He illustrated this with the following example:

> Imagine a section from a geography text about an unfamiliar nation. An adult would bring to bear an elaborate nation schema, which would point to sub-schemata representing generic knowledge about political systems, economics, geography, and climate. Each subschemata would have its own infrastructure and interconnect with other subschemata at various points (Anderson, Spiro & Anderson, 1978, p. 14).

Anderson's work advanced and expanded the understanding of schema theory that later became incorporated into the CLT model of human cognitive architecture. He advanced the cognitively-directed research of predecessors including Frederick Bartlett (1932) and Ausubel (1963, 1978) who developed the pedagogical strategy of advance organisers to activate prior knowledge and link it to new knowledge. As a result Anderson validated and brought clarity of definition to the mechanisms underpinning cognition during learning.

4.2.6 George Miller (1920–2012): Short-term memory limits

Miller's (1956) landmark article titled "The magical number seven, plus or minus two: Some limits on our capacity for processing information" shed light on the invisible processes of cognition that contribute to learning. This discovery had implications for learning design since it defined limitations of short-term memory; by doing so, it also strengthened the evidence-based foundation of learning design.

While the experimental research of Ebbinghaus (1885) had been a catalyst for a renewed interest in cognition, Miller's refinement of understanding of cognitive processes, including the concept of chunking to explain schema formation, provided impetus for research both in psychology and education through contributing a more detailed understanding of memory functions and limitations. The deepening knowledge of human cognitive architecture meant that learning interventions could be designed to accommodate these limitations.

Miller's (1956) notion of short-term memory, while an advance on Ebbinghaus's model, was based on a unitary, passive view of memory that did not have subsystems. It was much later that the definition changed from "short-term memory" to "working memory" (Baddeley, 1992, 1996, 2000; Sweller, 1999, p. 4), implying an active rather than passive function, with ongoing models contributing to the refinement of understanding of its functions.

Following Miller's pivotal postulation of the limitations of short-term memory de Groot (1965) conducted research into thought processes using chess novices and experts as subjects. His experiments brought greater clarity to the understanding of long-term memory and its functions.

4.2.7 Adriaan de Groot (1914–2006): Novice–expert differences; think-aloud protocols; retrieval of chunks; domain-specific knowledge in disciplines

Adriaan de Groot (1965), psychologist and chess master, combined these two fields (Gobet,

2006) and conducted experiments that provided insight into the structure and functions of long-term memory. As this research direction was continued by Simon and Chase (1973) it is also discussed in this section.

De Groot's work was grounded in the tradition of cognitive researchers who had laid the foundation of schema theory. His work is regarded as "a harbinger of the cognitive revolution in psychology that would occur in the early sixties (Gobet, 2006, p. 236).

De Groot aligned his research with the chunking theory of expertise as proposed by Miller (1956); his research both validated and extended the knowledge of long-term memory schemas through the study of differences in novice and expert thought patterns (de Groot, 1965; Long, Singh & Snitkof, 2005).

De Groot conducted experiments to investigate why chess grandmasters usually beat less experienced players. Some possibilities included the superior ability to search through the consequences of moves to find the best move or alternatively to search through a larger range of moves than less experienced players. De Groot found no evidence to support the supposition that game superiority was a result of this type of problem-solving skill but identified a single difference: the number of game board configurations memorised by the more advanced players. De Groot tested this hypothesis by showing masters and grandmasters actual game configurations for five seconds then asking them to reproduce the configuration from memory. They memorised the configurations to a high degree of accuracy. Less experienced players demonstrated far less accuracy. De Groot observed that strong chess players make use of past experiences and memorised board positions, drawing on prior knowledge schemas for demonstrating expert behaviour (Gobet and Simon, 1996; Sweller, 1988, 1999; Sweller, Ayres & Kalyuga, 2011).

Chase and Simon (1973) extended de Groot's findings by adding another dimension to the chess experiments. They placed chess pieces in random configurations for advanced and less experienced players to memorise. There were minimal differences between expert and novice players: they performed equally poorly in memorising random board configurations (Ericsson, Charness, Feltovich & Hoffman, 2006; Sweller, Ayres & Kalyuga, 2011).

These experiments explained chess expertise by the process of evoking game moves from a LTM storehouse of thousands of memorised board configurations and not from an ability to think through ingenious or unique moves. How is this skill acquired? Through deliberate practice for around ten years that is consistent, accurate, continuous and is motivated by the direct intention of improving performance (Ericsson, Krampe, & Tesch-Romer, 1993; Sweller, Ayres & Kalyuga, 2011).

There are two key pedagogical implications of these findings. First, increased problem-solving skill in domain-specific disciplines is directly related to the volume of stored problem configurations and their associated moves. It is not due to the acquisition of general or unspecified problem-solving skills (Sweller, Ayres & Kalyuga, 2011). Secondly, if this finding is extrapolated into learning environments, it signifies that the enormous storage capacity of long-term memory for expertise should be engaged through appropriate teaching and learning strategies at an early stage.

This does not imply that learning should be less meaningful and relevant to learners, or that learning processes should be forced, mechanistic or dehumanised. It points to learning experiences that cover the full spectrum of objectives as expressed in Bloom’s Taxonomy (1956) within specific knowledge domains. In summary, the research of de Groot (1965) and Simon and Chase (1973) brought to light the finding that since human cognitive architecture is uniquely optimised for the acquisition of expertise, teaching should align with this capability, supported by the direct teaching of domain knowledge until learners gain a critical mass of prior knowledge (R.C. Clark, 2011; Clark, Kirschner & Sweller, 2012; Kirschner, Sweller & Clark, 2006). By extension, learning should focus on the development of domain-specific expertise as early as possible while viewing learners holistically through the lens of the full range of their interests, aspirations and affective characteristics.

The implications of the findings of de Groot and Simon and Chase for the CLT model of human cognitive architecture are discussed in Chapter 5.

4.2.8 Richard Atkinson (1929–) and Richard Shiffrin (1942–)

Atkinson and Shiffrin (1968) proposed the multistore model of memory (also known as the modal model) to explain remembering and forgetting. The multistore model continued the research tradition of psychologists investigating information-processing mechanisms, who "seek to explain the relations between observable stimuli (input) and observable responses (output) by describing activities that intervene between input and output" (McInerney & McInerny, 2002, p. 75). Atkinson and Shiffrin (1968) use the term capacity in learning to describe how much information can be stored within three key memory systems (Figure 4.1),

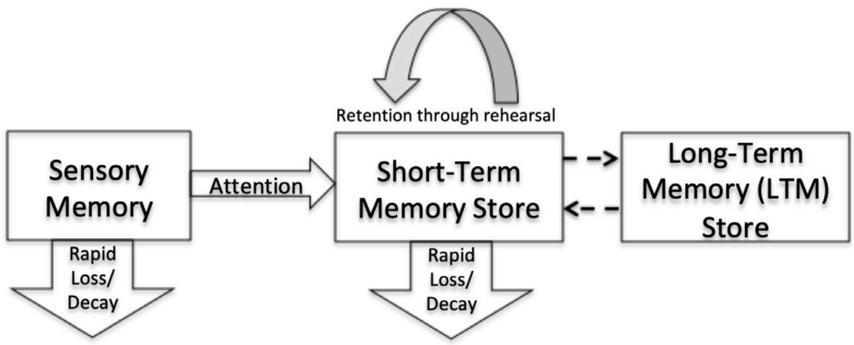


Figure 4.1 The multistore model advanced by Atkinson & Shiffrin (1968)

Notes: This model provides an explanation of the processes governing memory capacity (diagram adapted from Atkinson & Shiffrin, 1968).

This model describes memory systems that consist of three separate stores: a sensory register, short-term memory (STM) and long-term memory (LTM). In this model, information passes from store to store in a linear way, similar to a computer-based information-processing model with input, processing and output functions. Encoding is the way information is processed in order be stored in memory and three main methods of encoding information have been described. First, through visual stimuli (graphic images); secondly, through acoustic input (sound); and thirdly, via semantic input (meaning). In addition, other areas of input need to be recognised and acknowledged, even though they may not form part of the key research in CLT. For example, touch is a vital sense for learning in many areas especially for the sight impaired (e.g. learning to read braille) and learning in particular domains such as massage therapy or medical diagnosis through palpation. Each sensory mode provides input with varying levels of importance in different situations e.g. taste and smell for cooking and other disciplines that have an olfactory aspect.

In the input phase, information is detected by sensory faculties and enters the sensory memory. If attention is given to this information, it enters the short-term (working) memory. After arriving in short-term memory, information is transferred to the long-term memory if it is rehearsed or practiced. If this does not occur, then information fades from memory through decay or displacement. Each store is a unitary structure and has its own characteristics in terms of encoding, capacity and duration (Atkinson & Shiffrin, 1968; Gott, Kane & Lesgold, 1995).

Encoding of information by rehearsal was described by Atkinson and Shiffrin as maintenance rehearsal, consisting of repetition of information. Shiffrin later explained that rehearsal could be elaborative (Raaijmakers, & Shiffrin, 2003). The main emphasis of the multistore model is on structure and underplays the process elements of memory (e.g. it only focuses on attention and maintenance rehearsal). Elaboration rehearsal involves a more meaningful analysis of learned materials (e.g. images, thinking, associations, etc.) of information and leads to better recall, for example by the learner attributing meaning to words or linking them with prior knowledge. These limitations are dealt with by the levels of processing model posited by

Craik and Lockhart (1972).

Criticisms of the Aktinson and Shiffrin model include that it is oversimplified (Baddeley & Hitch, 1974), for example its suggestion that both short-term and long-term memory each operate in a single uniform fashion. In addition, it has also been criticised for being a passive, uni-directional or linear model (McLeod, 2007). However, this model has undergone some developmental revisions to refine aspects of it in response to criticism and further research. Baddeley and Hitch (1974) critiqued the working memory model of Atkinson and Shiffrin as being inadequate to explain higher level functions, outlining a more complex model that includes a central executive.

4.2.9 Alan Baddeley (1934–) and Graham Hitch (1974–): Working memory

Baddeley and Hitch (1974) published an article on working memory in which they asserted that despite over a decade of rigorous research on the subject of short-term memory (STM), virtually nothing was known about its role regarding normal human information processing. They asserted that the multistore model by Atkinson and Shiffrin (1968) did not reflect the complexity of memory systems and therefore sought to provide a more comprehensive model which went through a number iterative of refinements over the following three decades, for example the addition of an episodic buffer to the earlier model (Baddeley, 1992, 2000).

The initial model of working memory proposed (Baddeley & Hitch, 1974) consisted of a sensory memory which was prone to decay as well as two “slave systems”: a visuospatial sketchpad for processing visual information and a phonological loop for processing audio information. The phonological loop was also equipped with two sub-systems: a phonological store for holding speech-based information for 1–2 seconds and an articulatory control process used to rehearse as well as store verbal information that entered via the phonological store.

Visual and spatial information entering via sensory input would be managed by a central executive en route to being encoded in long-term memory. In this model, the central executive was therefore responsible for monitoring and coordinating the two slave systems. The model was later expanded (Baddeley, 2000) since the model did not explain some learning processes adequately, specifically the temporary buffering of information. The modification included the addition of an episodic buffer which has been defined as a backup store as well as a line of communication between the components of working memory and long-term memory (Baddeley 2000).

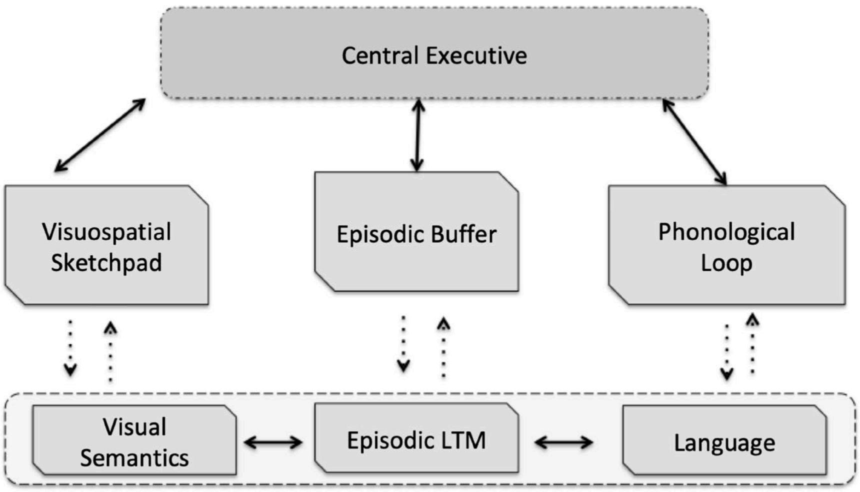


Figure 4.2 Baddeley and Hitch's modified working memory model

Notes: This model includes a central executive function as well as an episodic buffer function. Diagram adapted from Baddeley (2000).

The implications of this model for CLT have been that the pedagogical use of two processing channels (audio and visual) presented the capability of lowering cognitive load through sharing information between both channels through the modality effect. Sweller, Ayres and Kalyuga (2011, p. 44) asserted, "Under some circumstances … effective working memory capacity may be increased by using both processors. For this reason, the division of working memory into separate auditory and visual processors has important instructional implications”. The pedagogical implications of the modality effect are further explained:

> The modality effect is closely related to the split-attention effect. According to cognitive load theory, the split-attention effect occurs when learners must process separate but related sources of information that cannot be understood without mental integration. The cognitive resources required to effect this integration are unavailable for learning and may exceed the available capacity of working memory ... an alternative way of dealing with split-attention conditions [is posited] by engaging both auditory and visual channels of information in working memory rather than just the visual channel. For example, rather than presenting a diagram and written text that rely entirely on the visual channel, a diagram and spoken text relying on both auditory and visual modalities are used (Sweller, Ayres, Kalyuga, 2011, p. 129).

Baddeley and Hitch’s (1974) model and Baddeley’s (2000) updated model of working memory were further extended by the work of Allan Paivio (1971, 1986, 2010).

4.2.10 Allan Paivio (1925–2016): Dual coding theory

The next significant contribution to the model of working memory during the 1960s was dual coding theory (DCT) developed by Allan Paivio (1986) which further defined the specific functions of working memory in terms of two separate processing channels : “Dual coding theory (DCT) explains human behavior and experience in terms of dynamic associative processes that operate on a rich network of modality-specific verbal and nonverbal (or imagery) representations” (Clark & Paivio, 1991, p. 149).

Paivio (1986) proposed an active, dual coding theory that defined working memory functions assigned to separate channels in the form of an audio channel and a visuospatial sketchpad. Baddeley and Hitch (1996) later defined executive functions of working memory in their model. Together, these functional discoveries provided increased insight into the specific memory functions activated during learning, therefore providing greater clarity for informing learning design; effectively, each functional discovery enabled the generation of strategies that could be aligned to it.

Paivio's theory is foundational to both CLT and Mayer's cognitive theory of multimedia learning (CTML)(Mayer, 2005), since it informs the format and use of different forms of media (graphics, text, audio, animation) for maximising the processing capability of working memory. This is achieved through the use of specific strategies that harness the underpinning mechanisms of working memory by engaging both channels.

Mayer (2005) explains the relationship between the two channels in this model as parts of a highly connected and mutually interactive system. Informational elements may enter through either channel but learners may convert the representation in one channel for processing in the other channel. For example, the word tree in the logogens channels can be converted to an image of a tree in the imagens channel and vice versa. By harnessing this process, "cross channel representations of the same stimulus play an important role in Paivio's (1986) dual coding theory" (Mayer, 2005, p. 35).

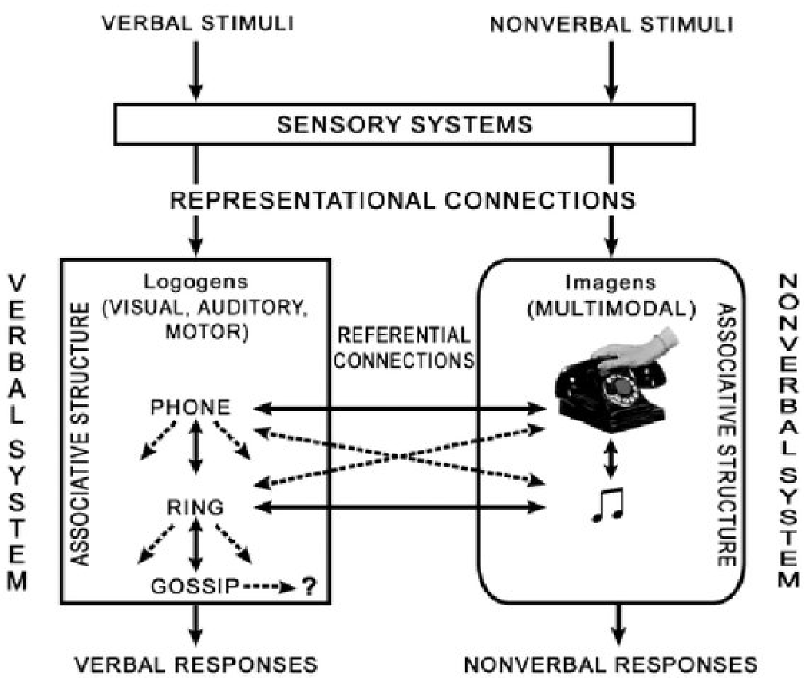


Figure 4.3 Dual coding theory model developed by Paivio (2010).

Notes: This model defines mental representations in terms of two independent subsystems: the verbal logogens (spoken, auditory, written, motor) and the nonverbal imagens (mental images, nonverbal representations). In this model, associative connections exist within each subsystem and referential connections serve as links between the two subsystems. This model of dual coding theory was published in The Mental Lexicon, 5(2), p. 209 doi: 10.1075/ml.5.2.04pai. Image used by permission, John Benjamins Publishing Company, Amsterdam/Philadelphia (https://benjamins.com/catalog/ml).

Effectively, dual coding theory is a “systematic analysis of the psychological phenomena associated with the concept of mental representations” (Paivio, 1986, p. vi). This theory underpins the instructional design processes required in creating instructional interventions that include combinations of media such as audio and visual representations in more than a single format and the conditions under which instruction can be optimised in support of schema formation and automation – and therefore intellectual growth. Learning involves the mental integration of separate knowledge elements in different multimedia formats into units of integrated, coherent meaning (Diezmann & Watters, 2002).

Concurring with this definition, Mayer (2005, p. 33-36) summarises the key assumptions related to learning with multimedia. These are the existence of dual processing channels (Paivio, 1986), the limited processing capacity of each channel (Chandler and Sweller, 1991; Paivio, 1986) and active processing “in order to construct a coherent mental representation of their experiences” (Mayer, 2005, p. 36). Ineffective instruction forces learners into unnecessary processing of “mutually referring information such as separate texts and diagrams” (Chandler & Sweller, 1991, p. 1). Specific instructional approaches are therefore required to take advantage of the dual processing functions of working memory.

The dual coding capability of working memory within human cognitive architecture has positive implications for instructional design using multimedia. As CLT is an instructional design theory, it is concerned with applying theoretical constructs of memory to the context of learning interventions. Driving this need is the assumption that working memory has limited capacity in both number of elements (Miller, 1956) and duration of persistence of elements (Cowan, 2010). In particular, the question may be asked of all theoretical constructs, "What impact does this exert on the management of cognitive loads?" Dual coding theory provides a specific answer to this question.

Dual coding theory provides a model for the efficient management of cognitive loads in working memory by increasing working memory load-bearing capacity. This is facilitated through distributing knowledge elements across two pathways under certain conditions, specifically, the elimination of extraneous load by structuring learning materials so that visual and audio input is devoid of meaning when viewed as separate elements.

Dual coding theory provided pedagogical strategy for increasing the capacity of working memory which became incorporated into CLT as the modality effect (Sweller, Ayres & Kalyuga, 2011). An additional strategy for managing the inherent weaknesses of working memory (Miller, 1956; Cowan, 2010) was the construct of long-term working memory, which is discussed in the next section.

4.2.11 K. A. Ericsson (1947–) and W. Kintsch (1932–): Long-term working memory

Long-term working memory (LTWM)

Ericsson and Kintsch (1995) effectively advanced the understanding of how expertise is acquired through their long-term working memory theory and model where:

> cognitive processes are viewed as a sequence of stable states representing end products of processing. In skilled activities, acquired memory skills allow these end products to be stored in long-term memory and kept directly accessible by means of retrieval cues in short-term memory, as proposed by skilled memory theory.

This model is a theoretical construct that provides a mechanism for the effective management of cognitive load in working memory (Sweller, Ayres & Kalyuga, 2011, p. 48) by bypassing the inherent weaknesses of working memory. Sweller (2010) observed that the key issue in learning design is managing the loads in working memory with the purpose of automating long-term memory schemas efficiently. While much research has been conducted in defining and attempting to manage cognitive loads imposed on working memory during learning, LTWM brings the purpose of managing cognitive loads to the fore and provides a pedagogical “workaround” to managing the limitations of working memory. This is achieved by bypassing working memory through schema automation

(Feltovich, Prietula & Ericsson, 2006; Sweller, Ayres & Kalyuga 2011). Once automated through the integration of multiple chunks into single schemas, processing capacity is released in working memory. This is through the mechanism of combined chunks entering working memory as single elements, where non-automated schemas would impose onerous loads on working memory resources, leaving few if any resources available for building schemas (Sweller, 1988). LTWM has profound implications for learning design, curriculum design and program delivery; this construct can only be activated where time is allocated to allow learners to engage with learning to the point of unconscious mastery.

Additional pedagogical workarounds to compensate for a limited working memory include early research into expert learning (Ericsson, 1988). In this theory, which was supported by rigorous empirical experiments, three key factors emerged regarding the development of expertise. First, encoding of knowledge through associations that are meaningful within the semantic memory structures of learners i.e. memory related to the lives and experiences of learners; secondly, retrieval cues that are associated with the automated schema – a construct referred to as a retrieval structure (Chase & Ericsson, 1982a); and thirdly, rehearsal, or practice of the memorised schema at a pace that is controlled by the learner for the purpose of speeding up learning.

Gobet (2000) observes that the study of expert behaviour and achievement is a significant research direction in cognitive science. He cites numerous cognitive theories that have arisen from this research, including the following:

1. Chunking theory (Chase & Simon, 1973)
2. Skilled memory theory (Chase & Ericsson, 1982a, 1982b)
3. SOAR (state, operator and result) (Newell, 1990), a cognitive model for designing computational constructs for simulating human thought
4. ACT (adaptive control of thought) (Anderson, 1983), a cognitive computational model that explains how human thought processes work
5. Template theory (Gobet & Simon, 1996), an advanced model based on the chunking theoretical model posited by Miller (1956).

The importance of schema automation as a goal of learning design cannot be over-emphasised as a strategy for aligning learning with the structure and functions of human cognitive architecture. Harnessing LTWM represents a mechanism at the nexus of the interrelationship between working memory and long-term memory, which has implications for curriculum structure and learning delivery. In other words, while the benefits of harnessing this mechanism are significant, the use of it implies in-depth teaching of core curriculum concepts with learners engaging in sustained rehearsal or practice over extended time frames (Ericsson, Krampe & Tesch-Romer, 1993; Marshall & Werder, 1972) until mastery is achieved by learners in both understanding and executing processes associated with expertise.

This approach may challenge traditional models of learning delivery that may be structured in short, disconnected time periods with frequent changes between subjects, or methods that limit learning outcomes by truncating learning experiences before full schema automation is achieved by learners, or exert artificial time pressure on learners by allocating insufficient time for expertise to be attained (Bloom, 1968, 1984; cf. Dreyfus & Dreyfus, 1980).

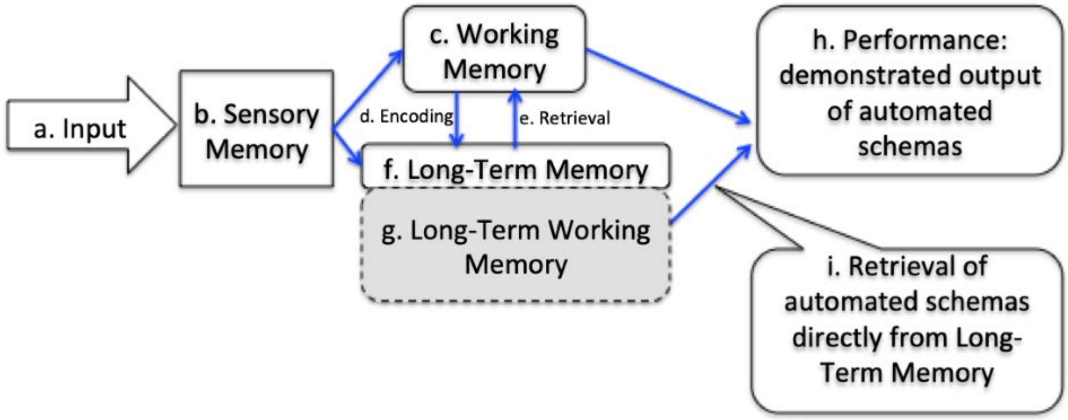


Figure 4.4 Overview of the long-term working memory (LTWM) mechanism.

Notes: This model, adapted from Ericsson and Kintsch (1995), has been incorporated into CLT as one method of bypassing the limited processing capacity of working memory.

Figure 4.4 illustrates the retrieval of automated schemas directly from long-term memory (f.) thereby bypassing the limited working memory as follows: a. input b. sensory memory c. working memory d. and e. usual process for encoding and retrieval of schemas information for working memory f. long-term memory g. long-term working memory (LTWM) representing fully automated schemas in long-term memory h. fluent performance or demonstrated output – an indicator of automated schemas (Sweller, 1999, p. 44) i. the pathway of automated schemas directly to performance (see h) by bypassing the usual encoding (see d) and decoding (see e) processes. The relationship between long-term memory (see f) and LTWM (see g) is that they form part of the same system but LTWM represents fully automated schemas.

4.2.12 John Sweller (1946–)

By the 1980s a sufficient understanding of the building blocks engaged during learning had developed to explain learning in terms of a limited working memory and an unlimited long-term memory.

While the development of this model had emerged through multiple studies over almost a century, it was in the 1980s that Sweller (1988) made experimental discoveries that could not be satisfactorily explained by existing theories. He began to explain complex learning processes in terms of a unified model of human cognitive architecture (de Jong, 2010; Sweller, Ayres & Kalyuga, 2011, p. 242), defining processes at the nexus between a limited working memory and an unlimited long-term memory during learning with the purpose of generating novel learning design interventions that maximised intellectual development during learning (Sweller, 1988).

The pivotal experimental discovery of CLT related to the different learning mechanisms activated for novices and experts. This discovery resulted in the explanation of problem-solving as a weak learning strategy for novices (Sweller, 1988, 1999, 2006a) and was a catalyst for research into the functions of human cognitive architecture during learning and specifically the management of the loads imposed on working memory during learning. This single finding is profound in its implications for teaching and learning as it validates the assertion that not all teaching results in effective and efficient learning; therefore, underpinning cognitive mechanisms need to be given attention during the process of learning design in order to engage these mechanisms optimally. Moreover, CLT links a theoretical model of the mechanisms of learning to pedagogy; it explains the activation of cognitive mechanisms underpinning the processes whereby novices progress towards expertise.

Sweller's experiments deepened the understanding of human cognitive architecture through the addition of descriptors for three types of cognitive load constructs (intrinsic, extraneous and germane) and paved the way for new research into the field that became known as CLT. Significantly, CLT arose at a time when multimedia and online learning was in its infancy and CLT quickly became used to explain pedagogical processes involved in multimedia learning through the cognitive theory of multimedia learning (Mayer, 2005). Multimedia elements in online learning environments (such as graphics, audio, text, video, and animation) had the capability of being aligned with cognitive functions for example through the modality effect (Sweller, Ayres & Kalyuga, 2011) which was derived from Paivio's (1986) dual coding theory.

CLT has had two different eras of development. In this study they are referred to as the early and late CLT eras. During the early era, research was based on experiments related to problem solving where Sweller (1988) used the model of human cognitive architecture to conduct experiments that led to explanations of why problem solving was a poor learning strategy for novice learners. Key learning effects arose during this era as well as their application to multimedia environments (Mayer, 2005).

In the late era of CLT, its theoretical basis was upgraded to an evolutionary model, in which learning was categorised into biologically primary and secondary classes of knowledge (Paas & Sweller, 2012; Sweller, Ayres & Kalyuga, 2011). About 15 years after Sweller's (1988) landmark article that brought CLT to the attention of the educational community, it underwent a process of theoretical modification in order to define these two categories of knowledge and their implications for teaching and learning. Sweller, Ayres and Kalyuga (2011) provide a definitive outline of this upgrade to CLT in their book, *Cognitive Load Theory*.

This theoretical shift in CLT was influenced by Geary's publication titled An Evolutionarily Informed Education Science (Geary, 2008). The key assertion in this upgrade to CLT was that two categories of information exist: primary biological knowledge that is inherited through evolutionary processes and secondary, or cultural, knowledge that is transmitted through formal instruction. The implication of this assertion is that primary biological knowledge, for example human movement and the ability to acquire the primary verbal language of communication, cannot be learned formally. On the other hand the capacity to acquire secondary information requires effort since humans are not wired to acquire it in the same way as primary knowledge. However, primary knowledge can be used to teach secondary knowledge. For example, "we appear to be able to process much larger amounts of information without strains on working memory when human movement is involved" (Sweller, Ayres & Kalyuga, 2011, p. 227).

This new research direction has resulted in the articulation of some additional CLT effects including the collective working memory effect, the human movement effect and embodied cognition using gestures and object manipulation (Paas & Sweller, 2012, p. 39).

Additional RCT-based research needs to be conducted to deepen the understanding of the specific mechanisms of primary knowledge and how they may be engaged to acquire secondary knowledge.

In summary, this chapter reviewed major contributory research to the unified model of human cognitive architecture posited by CLT and noted its upgrade to an evolutionary model. Moreover, it introduced key aspects of CLT that support its use as a learning design evaluation standard.

The following chapter provides a detailed overview of the unified model of human cognitive architecture. This model, which has been derived from the foundational cognitive research introduced in this chapter, forms the core framework of CLT that explains learning in terms of the functions and interrelationship of working memory and long-term memory.

Chapter 5 – The Unified Model of Human Cognitive Architecture Posited by Cognitive Load Theory

5.1 Introduction

Chapter 4 outlined the historical roots of CLT and its key building blocks that were derived from prior cognitive research into the structure and functions of working memory and long-term memory.

This chapter continues by presenting the complete model of human cognitive architecture posited by CLT which represents a unified view of these historical research findings (Sweller, Ayres & Kalyuga, 2011, p. 242). The interactions between working memory and long-term memory are explained and the pedagogical effects arising from this model are illustrated and outlined. The purpose of this explanation is to define the consolidated knowledge base arising from CLT that educational practitioners need to understand in order to implement CLT strategies effectively.

Following the consolidation of the knowledge base of CLT research, the implications of the CLT model and the pedagogical effects arising from it are discussed. This discussion clarifies the suitability of CLT as an evidence-based standard for evaluating learning design for the purposes of this study. The chapter concludes with key criticisms of CLT and a discussion of these implications for this study.

5.2 Overview of cognitive load theory

CLT is based on an information-processing model of learning (Miller, 1956; Miller, Galanter & Pribram, 1960) with stages of learning comprising input, processing and output. CLT originated with research by John Sweller (1988) into the cognitive states of novice learners during problem solving tasks and is based on a model of human cognitive architecture that assumes two factors:

1. a limited working memory that is restricted in processing capacity (Miller,1956) and duration (Cowan, 2010, 2014; Peterson & Peterson, 1959)
2. a long-term memory that has unlimited storage capacity but is limited by a slow rate of change.

CLT is based on a unified model of human cognitive architecture (de Jong, 2010) that seeks to understand and explain the interacting mechanisms between working and long-term memory during learning in terms of the loads imposed on working memory. These mechanisms include schema formation and automation (Sweller, 1988), how long-term working memory (LTWM) (Ericsson & Kintsch, 1995; Sweller, 1999; Sweller, Ayres & Kalyuga, 2011) can be harnessed to bypass the limitations of working memory and how dual channels of working memory (audio and visual) can be engaged to expand the processing capacity of working memory (Paivio, 1986, 2010; Sweller, Ayres & Kalyuga, 2011, p. 242). CLT aligns with research that suggests long-term memory contains the entire knowledge storehouse of a learner in structures called schemas (Anderson, 1977; Bartlett, 1932; Bransford, 1985; Cooper & Sweller, 1987; Iran-Nehjad & Winsler, 2000; cf. Piaget, 1975; Rumelhart, 1980; Sweller, 1988). Schemas, which Piaget (1954) defined as "a cohesive, repeatable action sequence possessing component actions that are tightly interconnected and governed by a core meaning", represent the total prior knowledge of the learners when they engage in new learning situations. The state and level of prior knowledge schemas is therefore the single most important predisposing factor when learners engage in new learning situations or try to solve problems (Gooding & Metz, 2011; Hailikari, Katajavuori & Lindblom-Ylanne, 2008; Kalyuga, 2009; Sweller, 1988; Sweller, Ayres & Kalyuga, 2011).

The critical focus that CLT places on the prior knowledge of the individual learner's personal knowledge base situates it within a learner-centric model of learning (Kalyuga, 2013; Sweller, 1988; Sweller, Ayres & Kalyuga, 2011). CLT is therefore aligned with contemporary research directions in education that seek more personalised approaches to teaching and learning (Bartle, 2015; Bray & McClaskey, 2015). CLT was originally focused on the cognitive processes engaged by novice learners advancing towards higher levels of expertise in formal learning environments and therefore some CLT effects relate specifically to novice learners e.g. the worked example effect and the goal-free effect. However, there are also effects that apply to learners with higher levels of expertise e.g. the redundancy effect and the expertise reversal effect. Thus, CLT applies to both novices and expert learners but with differential recommendations for instructional design and practice based on the levels of expertise and prior knowledge. With its key focus on the significance of the learner's prior knowledge, CLT presents a model of personalised learning that is differentiated from other models by its explanation of learning in terms of a complete model of the structure, functions and mechanisms underpinning working memory and long-term memory during learning, as well as the principles that govern these structures and functions.

All novice learners encounter the barrier of a limited working memory during learning at some point, which imposes loads of varying weights on the working memory system. To date, the specific loads imposed on working memory have not been quantitatively measured. However, the measurement of cognitive loads remains a key research direction in CLT (Zheng, 2018) driven by the quest to understand better how to design learning experiences that do not overload working memory capacity as schemas are being formed and automated, as well as how to optimise the use of cognitive processes within human cognitive architecture during learning. When translated into pedagogical practice, CLT proposes that instructional strategies should focus on maximising germane cognitive load during learning (Chandler & Sweller, 1991). This implies the reduction or elimination of extraneous cognitive load and also takes cognisance of intrinsic cognitive load through factoring the learner's level of prior knowledge into the design of learning interventions.

The cognitive load experienced by a learner represents the mental effort required to construct and automate long-term memory schemas (Moreno & Park, 2010, p. 10; van Merriënboer & Sweller, 2010) in complex learning tasks which are defined as tasks with high element interactivity (Sweller, Ayres & Kalyuga, 2011; van Merriënboer, Clark & de Croock, 2002). Complexity implies the need for learners to attain understanding of intellectual tasks that require integration of new knowledge with prior knowledge (Sweller, 1994).

Some mental effort is implied in all learning tasks. This may include a low element interactivity task like learning the meaning of a foreign word that requires no reference to other words to be understood or a complex task with high element interactivity such as balancing a chemical equation that requires a considerable base of prior knowledge to be understood. Tasks with high element interactivity can overload the processing capacities of working memory and learners with low levels of prior knowledge are more prone to experiencing cognitive overload.

CLT therefore views the learning process from the perspective of the loads imposed on the limited capacities of working memory during formal learning, as well as the underpinning cognitive mechanisms and functions that are activated during learning with the purpose of forming and automating schemas. This contrasts with behavioural approaches that view learning from the perspective of external learning behaviours or constructivist approaches that are not explicitly linked to a model of human cognitive architecture that explains learning in terms of the sub-mechanisms that are activated during learning.

5.3 Learning design and human cognitive architecture

The argument to this point asserts that the level to which human cognitive architecture is taken into consideration to inform learning design has implications for learning outcomes (Sweller, 1988, 1999). In terms of CLT, evidence-based teaching practice has two key factors:

1. understanding and explaining learning in terms of the structures and functions of cognitive architecture

2. the application of specific effects or strategies arising from CLT research (Sweller, Ayres & Kalyuga, 2011; Sweller, van Merriënboer & Paas, 2019) to manage cognitive loads imposed on working memory during the schema formation process. CLT therefore seeks to explain the mechanisms of learning using the above two criteria.

Sweller, Ayres and Kalyuga (2011, p. 76) summarised the core rationale for using CLT to inform learning design:

> We agree that learning efficiency may be a good indicator of schema acquisition and automation. If learners have acquired new schemas and can use them with less effort, then schema acquisition can be considered robust, even if the instructional method was more demanding. Nevertheless, instructional efficiency has an important role as it shows how efficient the learning process was, a key consideration of the cognitive load effects … Knowing how difficult or easy it was to follow an instructional design is critical to cognitive load theory. Despite these differences in approaches, both calculating the efficiency of training and the efficiency in using learned information in a test are important and can provide vital information relevant to instructional design (cf. Tuovinen & Paas, 2004).

5.4 Five underpinning principles of cognition

The following section outlines the five principles underpinning human cognition on which the CLT model of human cognitive architecture is based. These principles are a key contribution of CLT, which form a set of abstracted principles representing the governing functions of cognition during learning.

5.4.1 Principle 1: Long-term memory and the information store principle

This principle has its roots in experimental research by Bartlett (1932) and later by de Groot (1965) who investigated the thought processes of chess players during chess games, including novices, masters and grand masters. De Groot's conclusion was that the key difference between novices and experts hinged on the level of domain-specific knowledge of the expert stored in long-term memory (de Groot, 1965). Sweller (2010) incorporated this factor into the CLT model of human cognitive architecture, which assumes that human cognition is underpinned by a large store of information housed in long-term memory (Sweller, Ayres & Kalyuga, 2011; Tricot & Sweller, 2013). During learning, prior knowledge is drawn from this information store to transfer to new situations (Sweller, 1988; Sweller, Kalyuga & Ayres, 2011).

The implication of this principle is that since long-term memory forms the central repository of knowledge schemas, it is critical for problem solving.

A potentially negative implication of this mechanism needs to be considered in learning design, where Sweller, Ayres and Kalyuga (2011, p. 23) state that:

> Schemas held in long-term memory not only can render difficult problems easy to solve but can render simple problems very difficult to solve if the schema is erroneously assumed to provide an appropriate template. When we attempt to solve a problem by using an inappropriate schema because the problem looks as though it belongs to a particular category of problems but does not belong to that category, we have an example of einstellung or mental set (Luchins, 1942; Sweller, 1980; Sweller & Gee, 1978). Schemas stored in long-term memory may be essential for us to function but they also can prevent us from seeing what would otherwise be obvious (cf. Dweck, 2006–Mindset).

Transposing this principle to the classroom represents a pedagogy based on direct, explicit teaching in which learners gain mastery of the knowledge domain with strong levels of support in forming and automating schemas. The necessity for high levels of expert guidance for novices during the initial stages of learning (Kirschner, Sweller & Clark, 2006; Tuovinen, 2014) is due to the risk of cognitive overload as well as erroneous or poorly formed schemas by novice learners through unguided self-instruction. This mastery-based approach to learning (Bloom, 1968, 1984) already tends to be in use for subjects such as early reading, writing and motor vehicle driving i.e. a learning environment characterised by high levels of personal tutoring, support and guidance. CLT suggests a direct, guided approach to learning as standard pedagogical practice for all curriculum subjects due to the need for learners to develop a critical mass of prior knowledge in specific domains.

5.4.2 Principle 2: Schema theory and the borrowing and reorganising principle

This principle explains how information is acquired. Most information is acquired through imitation (cf. Rizzolatti & Craighero, 2004–Mirror neuron system), hearing or reading what others have written or said (Sweller, Kalyuga & Ayres, 2011) whether through simple transmission of knowledge using words or pictures or through complex multimedia interactions (Mayer, 2005). This implies that our base of existing knowledge has been borrowed almost in its entirety from schemas within the long-term memories of others (Sweller, Kalyuga & Ayres, 2011). However, this information is modified or constructed and not recalled verbatim – we do not remember precisely what we have seen, heard or read, but construct and derive a representation based on existing knowledge (Bartlett, 1932).

This principle of CLT raises a point of comparison with the constructivist view which assumes that learning is a self-constructed process as opposed to a process that requires high levels of support to form and automate schemas correctly in established domains of expertise (Kirschner, Sweller & Clark, 2006; Sweller, 1999; Tuovinen, 2014). CLT does not oppose the notion of self-constructed learning but suggests the need for a critical mass of accurate, domain-specific prior knowledge that enables ongoing learning to occur without overloading working memory or forcing a means–ends search process on the learner.

The essence of the constructive process reflected by schema theory is that a schema enables multiple elements, or "chunks" (cf. Derry, 1996; Miller, 1956) of information to be reorganised as a single integrated element (Sweller, 1999, p. 28). For example, a schema related to fluent reading, problem solving in mathematics or physics, allows a learner to classify the problem according to its solution mode. Advanced chess players access schemas that allow the classification of chess-board configurations according to the required moves (de Groot, 1965; Sweller, 2010). Due to its foundation in schema theory, CLT postulates that expert behaviour is determined by the number and sophistication of one's long-term memory schemas (de Groot, 1965; Ericsson, 1988; Sweller, 1988, 1999). In practice, expertise is defined as the learner's immediate recognition of problem types or categories, as well as the rules governing their resolution. The key indicator of expertise is therefore the fluent execution of domain-specific tasks or problem solving e.g. fluent reading and comprehension skills.

The borrowing and reorganising principle of cognition therefore reflects a counter-intuitive or non-traditional practice compared with dominant teaching methods in Western educational systems where constructivist approaches that include problem solving and discovery learning as teaching strategies are favoured (Kirschner, Sweller & Clark, 2006). This is despite the fact that the use of problem solving as a learning strategy for novice learners has been experimentally validated as a weak learning method (Sweller, 1988, 2006a). This weakness is due to the fact that low levels of schema formation and automation force learners to use means–ends analysis which is a resource heavy process that engages working memory capacity to such an extent that few if any resources are available to form and automate schemas – the goal of learning within an expertise framework. The implications of novice–

expert differences in cognitive processing for learning design are profound, requiring the adaptation of teaching strategies to ensure alignment with the optimal use of cognitive resources, processes and mechanisms.

5.4.3 Principle 3: Problem solving and the randomness as genesis principle

A person solving a problem is likely to draw first on an existing schema (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011) and where no schema exists a random search process will ensue to close the gap between the current problem state and the solution state. Consider the following simple example: a person is alone in a room that has three exit doors and is told that only one door is unlocked. Without any further knowledge, the person will need to engage in a random generate-and-test procedure to establish which door is unlocked. The results of the random generate-and-test procedure will either result in dead ends that need to be eliminated or a successful solution (the correct door) that can be stored for future use.

Consider a second example: when a mathematics student with a strong understanding of geometry and trigonometry is given a problem to solve e.g. to determine the length of the hypotenuse of a right-angled triangle, an existing schema or template (Sweller, Ayres & Kalyuga, 201, p. 23) will be activated that enables the learner to recognise the type of problem, the rules for solving it and then to solve it effortlessly. However, a novice who has not studied and understood the theorem of Pythagoras and therefore does not have pre-existing schemas for solving Pythagorean problems will need to engage in a search process in order to acquire the schemas required to solve this type of problem. In the absence of direct instructions from another person or source, the learner will need to engage in a creative random generate-and-test procedure which is "unavoidable when knowledge is unavailable" (Sweller, Ayres & Kalyuga, 2011, p. 33). The effectiveness of a randomly-generated move can only be determined after the move has been generated. Where a move proves to be a dead end it is eliminated but where a move advances the problem-solving process reliably, it is stored as a knowledge schema for future use. A learner who has not been exposed to explicit instructions on how to use the Pythagorean theorem will therefore be at a disadvantage due to being required to solve complex problems without having had access to previous explicit instructions.

The implications of the randomness as genesis principle for learning design are considerable. The random search process engaged by novices, also called means–ends analysis or search, draws heavily on working memory resources, leaving few (if any) resources to construct and automate schemas (Sweller, 1988). Since schemas represent the storehouse of prior knowledge that learners engage to solve problems, this principle therefore underpins the need for explicit and direct instructions and training of learners in the core principles within knowledge domains in order to build up a critical mass of prior knowledge schemas.

In addition, randomness as genesis principle is governed by another principle, the narrow limits of change principle (described in the next section), which suggests that schema development and automation occur very slowly for novices (Sweller, Ayres & Kalyuga, 2011, p. 101). This factor also has pedagogical implications because learning accrued by experts is subject to different conditions due to the existence of pre-formed schemas that facilitate the rapid integration of new knowledge.

5.4.4 Principle 4: Novice working memory and the narrow limits of change principle

This principle explains the mechanisms by which expertise is attained. Due to the structure of human cognitive architecture, expertise is attained at increasingly higher levels by the learner in incremental steps.

This aligns theoretically to the concept of Bruner's (1960, p. 13) "spiral curriculum" construct, where a pedagogy is proposed from which learners attain increasingly higher levels of expertise in domains with each re-visitation to the subject material. Gershon (2018) applies this principle in practice by illustrating how a complex subject such as quantum computing can be explained at five levels: a child, a teenager, a college student, a graduate student and a professional. Bruner based his work upon the hypothesis that "any subject can be taught to any child in some honest form at any stage of development" (Bruner, 1960, pp. 13, 52–54). In summary, in addition to viewing the teacher as the guiding expert in the learning environment, CLT also supports a "learner as growing expert" model (Dreyfus & Dreyfus, 1980), where expertise is incrementally increased until it is fully developed within a domain-specific area. This concurs with the view of Minsky (1975) who aligned characteristics of expertise to the model of human cognitive architecture. When expertise is attained at a high level through multiple automated schemas in a knowledge domain, a new principle is evoked: Expert working memory and the environment organising and linking principle.

5.4.5 Principle 5: Expert working memory and the environment organising and linking principle

Working memory operates under two specific limitations in processing capacity and duration of retention (Cowan, 2010, 2014; Miller, 1956) when novel information is introduced. However, it operates under no known limitations when elements are introduced from automated long-term memory schemas. Sweller, Ayres and Kalyuga (2011, p. 49) observe that:

> Working memory obtains information from long-term memory in order to provide an organised link to the environment. The environmental organising and linking principle allows organised information to be transferred from long-term memory to working memory in order for that information to be used by working memory to coordinate activity in a manner that is appropriate for a given environment.

The environmental organising and linking principle provides an explanation for how massive quantities of information are transferred from long-term to working memory in order to facilitate the complex functions of human cognition. Ericsson and Kintsch (1995) suggested a construct called long-term working memory (LTWM) to explain this phenomenon.

CLT operates under the assumption that novice–expert differences are a factor of relative schema development. Experts transfer complex, automated schemas to working memory as single elements, whereas novices, who do not have these schemas, resort to the default process of means–ends analysis (Sweller, 1988). The narrow limits of change principle provides insight into how the learning processes may be implemented without negatively impacting the information store. When automated schemas are thus formed and stored in long-term memory, the environment organising and linking principle serves to guide the use and application of the information (Sweller, 2015; Sweller, Kalyuga & Ayres, 2011).

5.5 Translating the theoretical model into a technological framework

As the current study involves translating the functions of the CLT model of human cognitive architecture into a technological framework, it is represented in Figure 5.1 as a unified model that takes the input–processing–output model as well as working memory (WM), long-term memory (LTM) and long-term working memory (LTWM) functions into consideration. The basic premise of this technological framework is to facilitate the design of learning that avoids the process of means–ends analysis for novices and supports schema formation and automation.

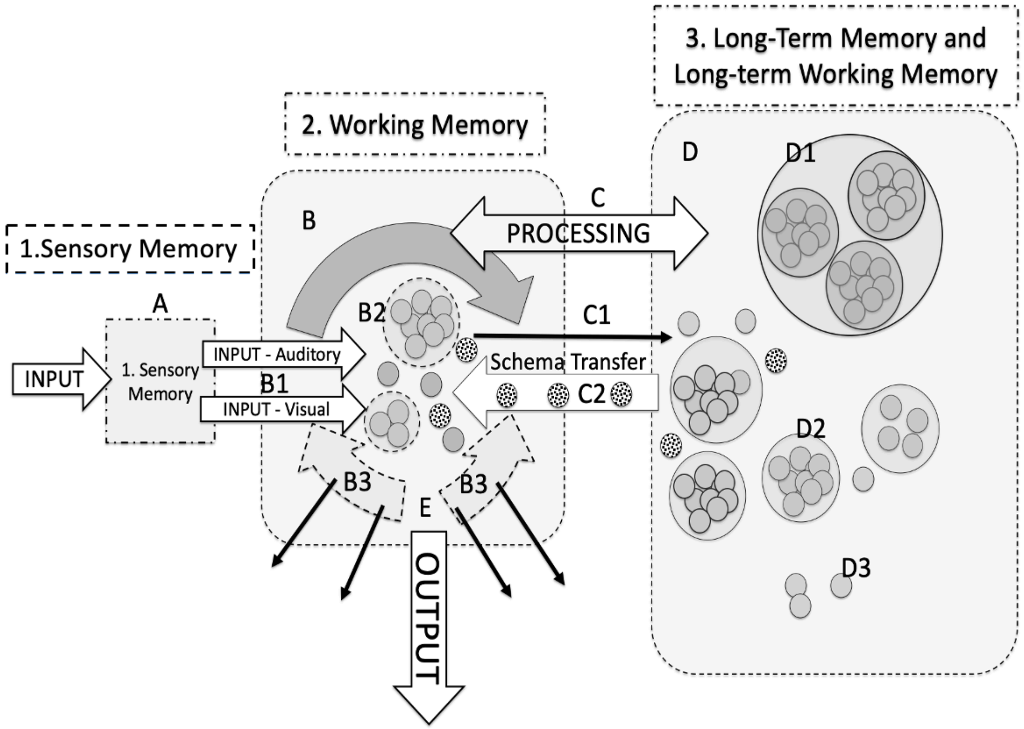


Figure 5.1 The CLT unified model of human cognitive architecture (diagram by D. Isaacson)

Key: Capital letters in parentheses in Figure 5.1 e.g. (A), (B) etc. align with the letters in the diagram (Diagram by D.Isaacson).

Notes: This figure provides a simplified overview of the unified model of human cognitive architecture posited by CLT (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011).

CLT is based on an information processing model of human cognition (Miller, 1956; Miller, Galanter & Pribram, 1960) and is grounded in studies of expertise (de Groot, 1965) that validate the learner's prior knowledge as the most significant factor impacting new learning (Sweller, 1988).

1. Cognitive load equates with the mental effort required to form and automate long-term memory schemas (Sweller, Ayres & Kalyuga, 2011).
2. CLT defines learning as persistent or permanent change to long-term memory schemas i.e. where no change to long-term memory has occurred, no learning has occurred. Sections 2 and 3 are related since as schemas are automated they become embedded in long-term memory where they are actively rearranged and recombined.
3. Three memory systems are represented in the CLT model: 1. Sensory memory (A); 2. Working memory (B); and 3. Long-term memory and Long-term Working Memory(D).
4. CLT has a specific focus on the structure, functions and processing interactions between working memory and long-term memory I in order to align learning with the structure and functions of human cognitive architecture.
5. Working memory (B) has dual processing channels (audio and visual) that may be harnessed through learning design that is aligned with the structure and functions of human cognitive architecture to increase the efficiency of learning according to the modality effect (B1)(see Modality effect).
6. Information chunks entering working memory via sensory memory (A) or long-term memory (D) are processed in conscious working memory which is limited in processing capacity and duration and subject to cognitive overload (see also Hassim, Bargh, Engell & McCulloch, 2009–Implicit working memory). The double-headed arrow (C) represents LTM schemas as a source of information, which are drawn upon to combine and recombine with elements in WM.
7. Within the CLT framework, working memory operates according to three cognitive load constructs: a. intrinsic cognitive load (inherent level of element interactivity of learning materials) b. extraneous cognitive load (load imposed by poor instructional design) and c. germane cognitive load (mental effort required to process intrinsic cognitive load).
8. Information chunks that are not formed and automated as schemas through attentional focus, deliberate practice and appropriate learning strategies soon undergo decay (B3) according to the curve of forgetting.
9. Information chunks entering the long-term memory store are subject to the narrow limits of change principle (C1), as represented by the narrow black arrow, and changes occur slowly for novices without a base of prior knowledge schemas. The smaller size of arrow (C1) does not imply that WM to LTM transfer is less important than LTM to WM.
10. Information chunks retrieved from long-term memory (C2) to working memory have no limitation on their size i.e. may contain multiple nested and integrated sub-schemas, and can function as a long-term working memory to bypass the limitations of working memory. The broad arrow (C2) represents LTWM function where sophisticated, automated schemas can pass from long-term memory to working memory. This process engages the environmental organising and linking principle (Sweller, Ayres & Kalyuga, 2011, p. 66).
11. Schemas of different sizes and levels of sophistication are processed and integrated into single schemas within working memory (B) and then stored in long-term memory which is assumed to have unlimited storage capacity (D). (B1) indicates the dual channels (auditory and visual) engaged with the modality effect.

The key implication of this unified model is that learning design requires specific strategies to manage the loads imposed on working memory within its limitations of processing capacity and duration of retention. The dual processing channels of working memory (auditory and visual) as well as LTWM may be harnessed through learning design to expand the capacity of working memory. The principles, effects and strategies arising from CLT provide guidelines for managing the loads imposed on working memory during learning to avoid cognitive overload

Additionally, the following functions are observed in this model (Figure 5.1):

1. the three memory systems (sensory, working and long-term memory)
2. the input–processing–output (information systems) functions represent a process that is multidirectional and in which existing information affects not only what happens in working memory, but also in the sensory memory (A) (Hitch, Allen & Baddeley, 2020). While processing is indicated as a working memory function to form and automate schemas, processing also occurs between long-term memory and working memory; for example, when the borrowing and reorganising principle operates through prior knowledge entering working memory from long-term memory (Sweller, Ayres & Kalyuga, 2011, p. 27)
3. the three cognitive load constructs articulated in CLT operate within working memory as represented by Section 2 of Figure 5.1.

Since the key issue related to the working memory is its proclivity to become overloaded during learning (Sweller, 1988), the following section provides examples of how cognitive loads may be balanced in working memory during learning under three pedagogical conditions.

5.6 Managing cognitive load during learning

Since working memory can become overloaded, CLT provides strategies for managing the intrinsic cognitive load of learning materials (inherent, unchangeable load of domain-specific content) with germane cognitive load (the mental effort required to process the load) while eliminating extraneous cognitive load (the load imposed by ineffective or unnecessary learning design components) present in learning interventions (Sweller, 1988, 1999; Sweller, Ayres & Kalyuga, 2011). In practice, learning can exceed the total processing capacity of working memory. The following examples in Figure 5.2 illustrate three representative load scenarios that may occur during learning:

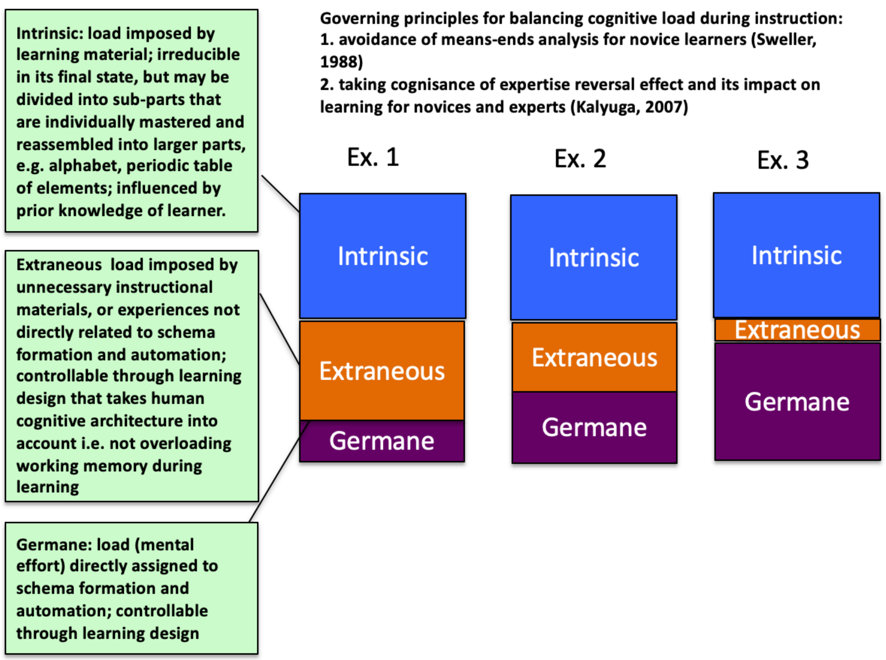


Figure 5.2 Three examples of possible cognitive load configurations

Notes: This figure provides an overview of three cognitive load balancing scenarios for the same intrinsic load (blue sections). Ex. 3 tends towards an ideal pedagogical application of CLT principles and strategies, where extraneous load is minimised (or eliminated) and germane (mental effort) load is matched to the processing requirements of the intrinsic load of domain-specific content knowledge. Germane cognitive load is therefore usefully defined as the mental effort exerted by the learner to process intrinsic load and is not necessarily seen as a separate load per se (Kalyuga, 2011a).

The three examples in Figure 5.2 may represent a. adjustments to a course delivered to a homogenous cohort in terms of prior knowledge and capability or b. adjustment to an intervention designed for an individual learner. CLEMS will need to include design features to accommodate both scenarios.

Example 1: In this example, germane load is lower than intrinsic load and is unlikely to be adequate to form and automate the multiple elements into single elements. In this case, an evaluation of the design of the learning intervention will need to be conducted to identify strategies that are not aligned with human cognitive architecture and replace them with validated, evidence-based effects.

Example 2: In this example, germane load has been increased and extraneous load reduced, demonstrating a more aligned pedagogical approach. However, the unduly high extraneous load is likely to introduce inefficiencies in the schema formation and automation process.

Example 3: In this example, the high level of germane load which matches the intrinsic load of the learning material, as well as the minimised level of extraneous load, is likely to produce high efficiencies in schema formation and automation. This example is the key driver for learning design as it has the goal of deliberately structuring the loads imposed on working memory in order to harness the capabilities of long-term memory.

The model of human cognitive architecture and the examples of cognitive load balancing during learning (Figure 5.2) represent the model used for informing learning design within a CLT framework. The purpose of the CLT model is to provide strategies that align learning interventions with the structure and functions of human cognitive architecture. The rationale for this alignment as a pedagogical priority is to achieve the formation and automation of long-term memory schemas in the most efficient way possible (Sweller, Ayres & Kalyuga, 2011). To accomplish this purpose, a range of experimentally validated effects or strategies has been developed by CLT researchers. These strategies comprise the learning design evaluation standard used in the new evaluation instrument.

5.7 The effects and strategies arising from cognitive load theory

The significance of CLT as a framework for informing evidence-based learning design is that it represents a working model of cognition and has also generated specific pedagogical guidelines, strategies, or effects, through RCTs (Mirza, Agostinho, Tindall-Ford, Paas & Chandler, 2020). These effects and strategies represent guidelines for designing learning interventions that take the structure and functions of human cognitive architecture into consideration. CLT therefore has produced a constellation of teaching strategies that is arguably the most consistent and comprehensive body of theory-based learning strategies in the literature of education (Mayer, 2005; Sweller, 1988, 1999; Sweller, Ayres & Kalyuga, 2011; Zheng, 2018). This is due to two factors that are not found in any other approach to the design–teaching–learning–evaluation cycle: first, its direct link to historical research findings regarding the structure and functions of working memory and long-term memory and secondly, its use of RCTs to validate the effects and strategies arising from this model.

The CLT body of knowledge consisting of effects and strategies is arranged in two categories in the following sections. The first category consists of general learning design principles (Table 5.1), which are the principles that set the broader context in which specific strategies operate and underpin all instances of learning design within the CLT framework. The second category consists of practices where theoretical principles have been transposed into specific pedagogical strategies (Table 5.2).

Table 5.1 General instructional design principles and effects arising from CLT research

General instructional design principles and effects arising from CLT	
Schema formation and automation	The purpose of CLT may be summarised as the management of three cognitive load constructs that impact the formation and automation of long-term memory schemas (Sweller, Ayres & Kalyuga, 2011, p. 101). Schema automation always remains the ultimate goal of learning interventions within the CLT framework. This is since schemas, when formed and automated, facilitate the release of processing capacity within working memory to process high element interactivity interventions (Leahy & Sweller, 2020); in other words, as automation occurs, more processing capacity becomes available in working memory. Variables impacting schema formation and automation include the prior knowledge base of the learner, mental effort applied by the learner, time applied to achieving automation and the structuring of the curriculum into part–whole tasks (Mayer, 2005; Sweller, 1988).
The time principle	This is a nuanced principle in CLT; the formation and automation of schemas for novices takes time as well as deliberate, persistent practice with carefully selected examples and expert support (Sweller, van Merriënboer & Paas, 1998). Time is frequently under-resourced in learning environments (Sweller, Ayres & Kaluga, 2011, p. 100) that are norm-referenced. As a result, partially formed schemas that represent unintegrated chunks of knowledge occupy excessive working memory resources and pose the risk of causing cognitive overload in the learner. A guiding principle in CLT is for sufficient time to be allocated to learning so that automation can be achieved in order for deep learning to occur through schema automation representing the acquisition of demonstrated expertise. This interpretation of time as a factor of learning design aligns with Bloom's (1968, 1984) research that advocates for a criterion-referenced model of learning. In this model, mastery learning is the goal for all students and flexible time is allowed for mastery to occur. While Bloom arrived at this conclusion through empirical research, CLT explains the underpinning cognitive mechanisms that are activated during the process of schema formation. Expertise is evidenced by learners having immediate recognition of problem types or categories, as well as the rules governing their resolution (Chapter 1).
Avoidance of means–ends analysis for novice learners	In problem-solving, means–ends analysis is "considering the current state, considering the goal state, and finding ways of reducing the differences between the two states" (Sweller, 1999, p. 154). Means–ends analysis is the default search process which novices engage during problem solving in the absence of prior knowledge schemas. Means–ends analysis is a resource-heavy process for working memory that leaves few (if any) resources available to form and automate schemas (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011). The deliberate design of learning interventions that avoid means–ends analysis for novice learners is a key driver of

	CLT in order to maximise limited working memory resources for learning (forming and automating schemas).
Element interactivity	Element interactivity is the extent to which learning requires individual items, chunks of information and schemas to be processed in limited working memory i.e. any separate items of information involved in mental processing. Element interactivity is a factor of the level of complexity of learning material combined with the prior knowledge of the learner. Element interactivity may be high or low, and complex learning is defined as learning that involves high element interactivity for a specific learner. CLT effects may be engaged to manage high element interactivity learning (Sweller, Ayres & Kalyuga, 2011, p. 93) that imposes a load on working memory which may exceed its processing capacity.
Expertise reversal effect	The expertise reversal effect expresses the experimental discovery that with increasing expertise, instructional procedures that are effective with novices can lose their effectiveness for experts. In experiments, this effect was observed only for complex or high element interactivity tasks (Kalyuga 2007; Kalyuga, Ayres, Chandler & Sweller, 2003; Kalyuga, Rikers & Paas, 2012; Sweller, Ayres & Kalyuga, 2011).
Guidance fading effect	Guidance fading is the instructional design practice of gradually lowering guidance as learners form and automate schemas, commonly applied through scaffolding techniques such as providing learners with: a. worked examples that have full explanations provided for each solution step (Sweller, 2006b) b. completion problems that fade the support and guidance (i.e. explanations are provided for part of the solution with learners expected to complete the remainder of the steps by themselves) c. traditional problems that require the learner to complete all problem-solving steps (Mayer, 2005; Sweller, Ayres & Kalyuga, 2011, p. 171).
Variability effect	Both near transfer and far transfer of knowledge (Thorndike, 1901; Pugh and Bergin, 2006) are important in learning design since they each represent different learning goals. While near-transfer skills facilitate solving isomorphic problems (similar surface and deep features), far transfer facilitates solving anisomorphic problems (increasingly variable surface features and similar deep features). CLT, which has its roots in the study of expertise (de Groot, 1965), has been tested for its propensity to facilitate knowledge transfer in learners (Sweller, Ayres & Kalyuga, 2011). A strategy suggested for facilitating far transfer is the variability effect through which “learners may be able to abstract schemas to transfer to long-term memory that incorporate knowledge of principles and learn when to apply those principles” (Sweller, Ayres & Kalyuga, 2011, p. 212). While early research suggested that worked examples could foster transfer skills, researchers have investigated other methods of structuring examples to promote transfer. For example, the inclusion of varied context examples in learning interventions (Clark, Nguyen, & Sweller, 2006) supports the variability effect.

Table 5.2 Effects and strategies arising from CLT research and examples of application

Effect	Definition	Explanation/examples of application
Worked examples effect	A worked example provides a step-by-step solution to a problem (Sweller, Ayres & Kalyuga, 2011). Studying worked examples results in better performance on subsequent tests of problem solving than solving the equivalent problems (Kalyuga, Chandler, Tuovinen & Sweller, 2000; Renkl, 2005) for novices engaged in high element interactivity learning activities. Worked examples can efficiently build the problem-solving schemas that need to be stored in long-term memory using the information store principle. Once stored in long-term memory, schemas can be used to solve related problems using the environmental organising and linking principle. This is a process of using scaffolding with practice examples to foster the understanding of problem types and the rules governing their resolution. This enables learners to abstract the principles in near transfer examples in order to transfer them to far transfer problems.	Example: Worked problems, completion problems and traditional problem-solving examples (Sweller, Ayres & Kalyuga, 2011, p. 107) provide a sequenced strategy for avoiding means–ends analysis, thereby building schemas through a forward-working process. A worked example can demonstrate not only the step by step processes but can also provide explanatory insight into underlying rules of organisation, higher organising principles and inferential connections between problem-solving steps. The use of worked examples requires consideration of the learner's prior knowledge levels as the worked example effect is more suitable for novices who need to build a prior knowledge base (Chandler, Kalyuga, Sweller & Tuovinen, 2001). Where advanced learners are given worked examples, the expertise reversal effect may be activated (Kalyuga, 2007; Sweller, Ayres & Kalyuga, 2011).
Problem completion effect	"The problem completion effect occurs when learners presented with worked examples to study perform better on subsequent test problems than learners asked to solve the equivalent problem" (Sweller, Ayres & Kalyuga, 2011, p. 99). The problem completion effect is closely related to the worked example effect (Sweller, Ayres & Kalyuga, 2011, p. 105). This effect is based on research evidence demonstrating that requiring learners to complete partially solved problems can be just as effective as worked examples (Paas & van Merriënboer, 1994b; Sweller & Cooper,	Example: Learners who are asked to solve a problem are only presented the first line of a worked example such as: Make 'a' the subject of the equation ab/c = d. In this problem, the first step that learners are shown is to multiply both sides of the equation by 'c' resulting in ab = dc. This step may also contain an explanation of the principle and thinking processes underpinning this operation i.e. to isolate 'a' by performing the same arithmetic operation (multiplication) on both sides of

	1985). A concern regarding worked examples was that it could lead to learner passivity, where problems are glossed over and not studied in depth. A paired alternation study mitigated the passivity problem, where learners studied a problem then solved a problem. However, an alternative strategy was to use completion problems, which is a worked example where learners are required to complete some of the solution steps (Sweller, Ayres & Kalyuga, 2011, p. 105).	the equation. The prompt to abstract this principle provides the learner with the opportunity to form and automate a schema that may be transferred to similar problems in future.
Continuous improvement (CI)	CI is a quality improvement concept practice arising from lean manufacturing (Deming, 1986), with a growing base of research supporting its adoption in higher education (Thomas et al., 2017; Yorkstone, 2016). CI represents an incremental improvement process that occurs through frequent small changes that are implemented, monitored and tracked over time as opposed to implementing major changes in single instances. CI is a sub-set of continual improvement, where improvement changes are implemented simultaneously at several levels (www.asq.org). One of the tools used to implement improvement changes is the plan–do–check–act cycle (or Deming cycle), which shares iterative and cyclical commonalities with Lewin's (1946) action research cycle of plan–act–observe–reflect (Meyer, 2000; McNiff & Whitehead, 2011) and the Reeves (2006) model of design-based research used in this study, consisting of cycles of analyse problem–develop solution–test solution–reflect on solution (Horvath, 2017).	In its broadest application, the concept of CI provides a framework for improving processes and practices. In this study, CI is an overarching framework for evaluating learning design with the goal of improving it incrementally through increasing alignment with an evidence-based model.
Goal-free effect	A strategy that phrases questions or examples to allow learners to engage a forward-working problem-solving process and thereby avoid the default means–ends search process (Sweller, 1988, 1999; Sweller, Ayres & Kalyuga, 2011).	For example, instead of asking to solve for angle x in a trigonometry problem, the problem is worded to ask learners to find all angles in the problem diagram. This subtle shift changes the cognitive process from backwards working to a forward-working mental process.

Split-attention effect	Split-attention is a phenomenon that occurs during learning when learners are required to split their attention between two or more sources of information that have been separated either spatially (distance) or temporally (time) (Chandler & Sweller, 1992; Mayer, 2005; Sweller, Ayres & Kalyuga, 2011)	The split-attention effect was initially identified in the context of worked example effect (Sweller, Ayres & Kalyuga, 2011). Worked examples where the learner's attention was split between information sources increased cognitive load, with negative learning effects. A single, integrated source of information leads to better learning outcomes.
Isolated elements effect	During the initial stages of learning, presenting complex material as a set of isolated elements of information that ignore relations between the elements may reduce excessive intrinsic cognitive load. Learning is enhanced if very high element interactivity material is first presented as isolated elements followed by interacting elements versions rather than interacting elements initially (Pollock, Chandler & Sweller, 2002; Clark, 2008b, p. 297; van Merriënboer & Sweller, 2005).	For example, learning to read often involves the initial learning of individual letters of the alphabet, then progressing to learning their associated sounds, followed by more complex learning interactions. Learning complex process sequences may be done more effectively when each element is learned and practiced to the point of mastery in isolation.
Redundancy effect	The negative effects on learning as a result of unnecessary information that imposes additional cognitive load on working memory resources. The presence of sources of information that do not contribute to schema acquisition or automation interfere with learning (Cooper, 1990).	Conditions for identifying redundancy: 1. where sources of information within a learning intervention can be understood in isolation (i.e. greater efficiency in learning is achieved where materials are complementary and cannot be understood in isolation i.e. not providing the same explanation in both channels); 2. learning materials that require high element interactivity for learners (i.e. learning is complex for the learner); 3. in multimedia environments, text must be presented concurrently in graphic, written and audio formats – this material must be complex enough to cause high cognitive load (i.e. redundancy occurs through overloading the working memory system with unnecessary, duplicated information – giving rise to extraneous cognitive load).

Modality effect	Multiple sources of information that are unintelligible in isolation result in less learning when they are presented in single modality as opposed to dual modality format (Low & Sweller, 2005; Mayer, 2005, pp. 6–7). Sweller, Ayres and Kalyuga (2001, p. 139) observed that: "The major instructional implication that flows from the modality effect is that under certain, well-defined circumstances, there can be considerable benefits to presenting information in a dual mode, audiovisual form rather than in a visual only form. Care must be taken to ensure that the conditions for the superiority of audio-visual instructions apply. The most important conditions, all of which flow directly from CLT, are that the audio and visual sources of information must rely on each other for intelligibility, element interactivity needs to be high and the audio component needs to be sufficiently short to be readily processed in working memory".	Example: A graphic representation of the 12 facial nerves is provided to nursing students in an online learning environment with labels A-L corresponding with nerves 1–12. An accompanying audio track is provided with explanations of each labelled nerve. The audio and visual information is therefore reliant on the other for intelligibility and for learners to infer meaning. This example illustrates that by engaging two channels of working memory (visual and audio) and by reducing visual search and associated split-attention situations when verbal information is presented in the auditory modality, learning can be facilitated (Sweller, Ayres & Kalyuga, 2011, p. 140).
Imagination effect	Imagining procedures or concepts enhance learning compared with studying materials under some circumstances (Cooper, Tindall-Ford, Chandler & Sweller, 2001; Leahy & Sweller, 2004; Leopold & Mayer, 2014). This effect is "not useful for low-knowledge students because of the heavy working memory load it generates for these learners" (Sweller, Ayres & Kalyuga, 2011, p. 194). Imagination as a learning strategy has similarities with the concept of sharing the visualised sequences of images that can be played in our minds (Chase & Simon, 1973b; Zolan, Strome & Innes, 2004, p. 23).	This effect may be illustrated by the example of a teacher who first engages learners in an intensive genetics workshop on the cell division functions of meiosis and mitosis. Rather than providing paper-based revision exercises to study, at the end of the workshop the teacher could ask learners to close their eyes and the teacher then talks the students through the key concepts and procedures in both mitosis and meiosis, asking the students to imagine the concepts and procedures. By using this strategy with students who already have a knowledge base, the teacher engages the principle that imagining procedures or concepts can enhance learning compared with the strategy of studying materials (Leahy & Sweller, 2004; Leopold & Mayer, 2014).

Self-explanation effect	"Students who explain examples to themselves learn better, make more accurate self-assessments of their understanding, and use analogies more economically while solving problems" (van Lehn, Jones, & Chi, 1992, p. 1). Self-explanation is part of the self-reflection process. Guiding this process is the principle that students need to reflect on correct examples (Mayer & Moreno, 2010). To elaborate on the above definition, the self-explanation effect is the effect that occurs when instructing learners to engage in self-explaining the connections between interacting units of information improves performance (Sweller, Ayres & Kalyuga, 2011, p. 187). There is caveat to this principle regarding the relative quality levels of self-explanations. High quality self-explanations form deep inferential connections, while low quality self-explanations consists of surface or shallow connections. High quality self-explanations are the most beneficial (Bisra et al., 2018; cf. Chi et al., 1989; Chi et al., 1994; Kalyuga 2009a, p. 305; Mayer, 2005, p. 272; Sweller, Ayres & Kalyuga, 2011; VanLehn, Jones & Chi, 1992).	Example: "Within a cognitive load theoretical context, self-explanations require students to establish the interactions that relate various elements of a worked example both to each other and to previous knowledge. While not specified in the self-explanation literature, to process these interacting elements requires sufficient working memory resources, as indicated by the narrow limits of change principle" (Sweller, Ayres & Kalyuga, 2011, p. 188).

Notes: Tables 5.1 and 5.2 provide the source information that could be contained in CLEMS. It is not the intention of the study to incorporate every effect arising from CLT into CLEMS, but to initiate the use of CLEMS that contains a database of effects suitable for beginning the process of analysing and improving pedagogical processes. This is since the goal of the study is to identify the conditions under which CLT effects can be managed within a technological framework. As CLEMS has been conceptualised within a CI framework, future iterations are intended to increase its knowledge database.

5.8 Criticisms and critiques of cognitive load theory

Criticisms and critiques of CLT have stimulated a robust debate in the literature, which have brought clarity and highlighted areas requiring further research. The following sections outline a range of criticisms and critiques which are interpreted and discussed in terms of the goals of the study.

5.8.1 Theoretical and methodological problems with cognitive load theory

De Jong (2010, p. 118) conducted a limited survey of 36 key CLT source documents to inform a critical overview of CLT, highlighting three key issues as follows:

a. The relative nature of cognitive load measures resulting in lack of objective measurement capability. In response to this point, de Jong's criticism therefore holds some validity since cognitive loads are always a subjective measure depending of the prior schematic development of individual learners (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011). While the measurement of cognitive loads is an ongoing research direction in CLT (Zheng, 2018), to date no quantitative measurement scale for the objective measurement of individual cognitive loads has been established. However, the most significant advance in this area has been made through the subjective measurement of cognitive loads via the Paas (1992) Scale.
b. A cumulative or overall rating of cognitive load does not provide insight for interpreting results in terms of CLT, since each contribution to learning by different cognitive loads is different. In response to this criticism, this conceptual issue raises the question of whether "the different types of cognitive load [can] be distinguished" (de Jong, 2010, p. 110). This is not a precise interpretation of CLT; for example, intrinsic and germane loads are directly related (Sweller, Ayres & Kalyuga, 2011), with germane load representing the mental effort required to process the intrinsic load of the learning material. Paas, Ayres

and Pachman (2008, p. 14) bring further clarity to this issue by providing definitions of mental load, mental effort and performance and their relationships:

> Mental load is the aspect of cognitive load that originates from the interaction between task and learner characteristics. It provides an indication of the expected cognitive capacity demands and can be considered an a priori estimate of the cognitive load. Mental effort is a second aspect of cognitive load, which refers to the cognitive capacity that is actually allocated by the learner to accommodate the resource demands imposed by the task, and thus can be considered to reflect the actual cognitive load. Mental effort is measured while learners are working on a task. Performance, the third concept of the assessment dimension of cognitive load, can be defined in terms of learner's achievements such as the number of correct test items, number of errors, and time on task. It can be determined while people are working on a task or thereafter.

c. Frequently used measures of cognitive load are not sensitive to variations over periods of time. In response to this criticism, de Jong's view has some validity. However, a key direction in CLT research consists of experiments to measure cognitive loads at various time intervals e.g. at the start of the learning event, during the learning event and after the learning event has been completed (Tuovinen & Paas, 2004).

5.8.2 The allegedly questionable scientific basis of cognitive load theory research

De Jong (2010) commented that CLT is positioned in such a way that makes it difficult or impossible to falsify i.e. to verify with a high degree of certainty that a learning effect was obtained by a specific strategy. The criterion of falsifiability as a condition of scientific veracity arises from Popper's experimental philosophy (Newton-Smith, 1995; Popper, 1959, 1963), which asserts that a theory may be regarded as scientific not through numerous positive outcomes from experiments but through its falsifiability i.e. a single example demonstrating it to be false, which is the criterion of falsifiability. Popper's approach engages the null hypothesis theory, where a single example of falsity is all that is required for a decisive proof according to rules of logic. The text book illustration of Popper's principle is that the statement "all swans are white" can be logically refuted by evidence of a single black swan (Popper, 1963).

Moreno (2010) also challenges the scientific nature of CLT on the basis that it is not derived from a positivist research paradigm and therefore cannot claim to be scientific. The foundation of this criticism is that the learning effects arising from CLT research provide post-hoc explanations for cognitive processes rather than direct observations of phenomena during experiments that may be tested and negated by observation of a single contradictory occurrence.

It is suggested that Moreno's (2010) and De Jong's (2010) criticisms may lack substance to the extent that cognitive processes and mechanisms are not the types of phenomena that can be evaluated by direct observation in terms of a positivist experimental process (Bartlett, 1932; de Groot, 1965; Gerjets, Scheiter, & Cierniak, 2009; Lichtman, 2006; Piaget, 1926; Sweller, 1988).

These criticisms evoke a philosophical debate regarding the nature of scientific theories and what may be considered scientific. To place this argument regarding the alleged unscientific nature of CLT experiments in perspective, the model used to derive CLT effects and strategies has been based on RCTs, a validated experimental model in psychology, rather than a Popperian model of absolute falsifiability, which is more suited to directly observable phenomena in hard sciences such as physics and chemistry. For example, in the hard sciences the characteristics of phenomena such as space, time, motion, gravity and predictability need to be understood for their properties to be harnessed for scientific development. However, the nature of these characteristics is challenged by quantum theory (Potter, 2008, p. 105) thus creating an apparent contradiction that may require a unified theory to accommodate explanations of both paradigms within a single framework (Newell, 1990).

In educational research, the complex functions of cognition cannot be observed with the naked eye which suggests that the principles of cognitive operation and interaction between memory systems can be tested in terms of the most well understood governing principles of working memory and long-term memory systems and their outworking in learning contexts. Ongoing experimental testing and replication rather than a single instance of refutation are required to understand learning effects, to define their conditions of operation and to determine their optimal application in learning environments. Potter (2008) expresses the process of arriving at conclusions in this way as a systematic and complex process that references other deductive and inductive conclusions. In CLT, the historical experimental discoveries inform current practice.

The criticisms regarding the lack of falsifiability of CLT therefore relate to the suitability of certain methodological tools to investigate a particular class of phenomena; for example, a physician would not use a thermometer in place of a sphygmomanometer for measuring blood pressure, or dismiss a patient's report of shortness of breath due to the patient being unable to prove it according to falsifiable criteria. Rather, a methodology that admits a range of plausible causes while understanding underpinning body systems and mechanisms is a more appropriate approach to medical diagnosis, with further testing being conducted to refine conjectures and arrive at satisfactory and useful diagnoses (Sandoval, 2004). The use of appropriate methodological tools to investigate cognitive phenomena (which by corollary implies the rejection of other less appropriate tools) does therefore not invalidate the experimental findings of CLT which are derived from a different research paradigm. In other words, interpreting CLT research within a paradigm in which its experiments were not conducted effectively sets up the logical fallacy of a “straw-man” (Walton, 1996) objection to CLT and is therefore a criticism that cannot be unequivocally accepted.

CLT literature reflects robust discussions regarding potential biases in its explanations of effects or phenomena as well as alternative explanations for effects identified through RCTs (Sweller, Ayres & Kalyuga, 2011). However, within this philosophical debate Sweller, Tindall-Ford and Agostinho (2020, p. 238) assert that “all cognitive load theory findings are falsifiable, constituting a major strength of the theory”. This assertion has validity to the extent that some CLT effects have not resulted in expected outcomes under certain conditions e.g. the outcomes of worked examples being modified by the learner’s prior knowledge (Tuovinen, 1999; Tuovinen & Sweller, 1999). In these cases, ongoing experimental validation is required to determine optimal conditions for achieving certain effects. However, the effects themselves are not dismissed due to their conditions of application being less than optimal. This illustrates the point that CLT is more suited to validation by psychological methodologies such as RCTs than Popperian, null hypothesis experiments.

In summary, the points of debate regarding the methodological paradigm in which CLT has been conducted are valuable to the extent that they highlight philosophical differences between positivist, realist and interpretivist research paradigms in terms of the a priori assumptions and a posteriori (Kant 1963, originally 1781) ontological and epistemological considerations applied in different experimental models.

It is the assertion of the researcher that positivist and interpretivist approaches to investigating phenomena may have insufficient congruence with the complex nature of educational research for it to be pedagogically useful in this study and to CLT in general. A more congruent ontological and epistemological framework appears to be offered by Critical Realism (CR), which views reality as multi-layered and multi-mechanistic (see Section 6.5). CR therefore offers an alternative, middle ground to the inductive processes of positivism and the relativistic framework of interpretivism. It does this by seeking to articulate the ontological perspective of multiple layers of reality and their underlying mechanisms that operate epistemologically within learning environments under different conditions.

5.8.3 Lack of a collated body of cognitive load theory knowledge

One of the major problems of CLT is that the research is distributed across disparate sources and has not been collated into a useful format for educators to implement with in situ learning environments. Other disciplines where evidence-based practice has become the norm such as medicine (Swanston, Schmitz & Chung, 2010), nursing (Benner, 1982; Highes, 2008) and psychology (American Psychological Association, 2005) have community-developed standards for supporting practitioners; however, this is still a nascent process in education (Lodge & Matthews, 2017). There is increasing interest in developing more accessible and useable formats for CLT; for example, a recent white paper was issued by the New South Wales Centre for Education Statistics and Evaluation (Centre for Education Statistics and Evaluation, 2017) titled *Cognitive load theory: Research that teachers really need to understand* which supports widespread adoption of CLT strategies in schools.

The call for the wider distribution of CLT findings is likely to be a catalyst for research initiatives to meet this need. The collation and dissemination of the CLT research knowledge base and its effective application in learning environment requires a systemic, methodological approach for managing its implementation on a large scale (Senge, 1990; Siemens, Dawson & Lynch, 2013; Siemens & Matheos, 2010; Uys, 2015). The current study is a contribution towards this goal by the proposed collation and systemisation of CLT knowledge within CLEMS for use by educators in the implementation, measurement and monitoring of CLT effects in practice.

5.8.4 Omission of mediation and normativity in cognitive load theory

Derry criticises CLT for its failure to "pay attention to mediation and normativity, both of which are distinctive aspects of human action" (2020, p. 5). Derry refers to mediation as the Vygotskian notion of establishing the learner's representation of knowledge within the context of social relationships, while normativity refers to the transmission of social and cultural norms of society. Normativity does not refer to social conventions but to "the means by which we mediate and organise experience" (Derry, 2020, p. 12). Both mediation and normativity therefore have the purpose of providing a context in which the reasoning capacities of the learners may be developed. Derry's issue with CLT is that it lacks the pedagogical strategies that take the contextualised humanity of learners into account and as a result is at risk of failing in the area of actualising human capacities (Brown, Collins & Duguid, 1989; Collins, 1991). Derry affirms the view that the transmission of knowledge needs to occur through direct, explicit instruction and also points out inherent weaknesses of inquiry and discovery learning (Kirschner, Sweller & Clark, 2006) but advocates for the need for an expanded view of learners that focuses beyond cognitive functions to a connection with the environment (cf. Gibson & Gibson, 1955).

Derry's critique of CLT may have some validity since CLT does not have specific pedagogies of situated cognition, mediation or normativity in the Vygotskian definition. CLT focuses primarily on the cognitive processes that are engaged during formal learning in specific knowledge domains, with attention to the limitations of working memory and the formation and automation of long-term memory schemas. However, Derry's view requires some modification since the research direction adopted by CLT does not assume that learning should be decontextualised from social, mediatory or the local environment, but retains a focus on its primary goal regardless of the context. Two of the five underpinning principles of

CLT define instructional effects in terms of links to the environment. These are the narrow limits of change principle and the environmental organising and linking principle (see Chapter 5) which explain the purpose and function of the environment in learning.

In recent years, CLT researchers have conducted research into areas such as motivation and engagement (Martin, 2016) and self-efficacy (Vasile, Marham, Singer & Stoicescu, 2011), which by inference may overlap to a greater degree with learning environments and their broader social contexts. Since the pedagogical effects of CLT have advanced using RCT experiments, this implies a slow rate of progress of research. However, as greater links between environmental, social and other external factors are investigated in terms of their impact on cognitive load, it is feasible to expect new understanding of CLT in these contexts to emerge.

In this study, the term heutagogy (Hase & Kenyon, 2001) has been adopted to represent the cluster of qualities and characteristics of learners that constitute self-directed learning capability. In terms of CLT, these qualities and characteristics are viewed as acquired knowledge that occurs through connections and interactions with the environment in all its forms.

5.8.5 The need for an expanded pedagogical vocabulary in cognitive load theory

An area of potential advancement in CLT noted by the researcher is to expand CLT terminology to express key ideas that are relevant to its pedagogical application. It is necessary to further develop this language to empower educators on a broad scale to implement CLT successfully.

First, CLT validates prior knowledge of learners as the most significant factor in contributing to new learning (Sweller, 1988) and some indicators of the different levels of quality of prior knowledge are nuanced in the literature (cf. Bartlett, 1932; Kalyuga, 2007; Sweller, Ayres &

Kalyuga, 2011). However, a clearer presentation of the hierarchical levels of prior knowledge in terms of their quality and stage of development is suggested for it to become useful to educators as a tool for personalising learning. These levels of the learner's prior knowledge schemas may include the following:

1. No prior knowledge schemas i.e. learner is completely unfamiliar with the new learning material
2. Incomplete prior knowledge schemas i.e. learner has some familiarity with the knowledge domain, could be experiencing "blocks"
3. Erroneous prior knowledge schemas i.e. learner is framing knowledge with incorrect concepts or analogies, or has incorrect mental representations of knowledge (Méheut, 2012)
4. Formed but not automated prior knowledge schemas i.e. learner is familiar with knowledge and concepts, but lacks applications and deliberate practice in authentic environments
5. Formed and automated prior knowledge schemas (near transfer) i.e. learner has clear understanding of principles and how to apply them to isomorphic examples
6. Formed and automated prior knowledge schemas (far transfer) i.e. learner has clear understanding of principles and how to apply them to anisomorphic examples, or new and variable situations
7. Expert application of formed and automated prior knowledge schemas i.e. learner has advanced understanding of the knowledge domain, a high level of heutagogical capability, situation awareness, as well as independence and creativity in applying principles to anisomorphic problems in authentic work contexts.

These proposed levels are useful for the purposes of this study in illustrating how prior knowledge states of the learner may be more clearly defined in terms of their diagnostic usefulness to educators. Moreover, these seven levels of prior knowledge directly address the question posed in Chapter 1 about how teachers can know the levels of understanding of their students. CLT provides a rational framework for supporting teachers in this diagnostic process (Philips, McNaught & Kennedy, 2010)

Secondly, CLT does not have an expressive language for defining specific barriers to schema construction and automation, where a barrier may be defined as troublesome knowledge (Perkins, 1999), bottlenecks (Middendorf & Pace, 2004), barriers (Falasca, 2011) or other classes of hindrance to advancing towards expertise within a knowledge domain.

The notion of barriers to learning is well established in the literature (Land & Meyer, 2016; Meyer, 2005; Meyer & Land, 2000, 2003, 2006; Pace, 2004). Teachers who have a more holistic view of learners including levels of prior knowledge, personal motivations and circumstances may devise targeted strategies to facilitate the removal of specific barriers to learning at a more granular level. For example, Skilbeck (1991, p. 47) observes:

> Understanding barriers and incentives to learning requires us to consider people's interests and motives, their conceptions of what learning entails and the benefits it brings, as well as their personal, domestic, economic and social circumstances. No general theory of learning has been produced to encompass this very large and diverse set of considerations. Individuals and circumstances differ and there are random elements at play. Still, why people choose to learn, what and how they learn and conditions that facilitate learning are important to know about, together with knowledge of the barriers and inhibiting factors which exist in society at large as well as in individual lives.

For this reason, a more exhaustive definition of barriers could inform the provision of more focused interventions for advancing learners towards expertise. CLT explains barriers to learning in terms of element interactivity. Sweller, Ayres and Kalyuga (2011, p. 62) stated:

> Element interactivity can be used to define "understanding" (Marcus, Cooper,

> & Sweller, 1996). Information is fully understood when all its interacting elements can be processed in working memory. A failure to understand occurs when appropriate elements are not processed in working memory. Information is difficult to understand when it consists of more interacting elements than can readily be processed in working memory. Low element interactivity information is easy to understand because it can easily and appropriately be processed in working memory.

Barriers to learning may emanate from different sources and have a broader definition than the cognitive explanation provided by CLT. For example, learners may have barriers related to understanding knowledge types including facts, concepts, processes, procedures or principles (Clark, 2008a, p. 50); they may have affective barriers such as low self-efficacy (Bandura, 1997a) or poor locus of control (Miller, Fitch, & Marshall, 2003; Norwicki & Strickland, 1973) or other factors related to self-determination (Deci & Ryan, 2012; Hase & Kenyon, 2001); they may have moral or ethical barriers to learning, where barriers to learning arise where learning contradicts a belief system (Bezzi & Happs, 1994), or they may have learning barriers related to stereotype threat (Steele, 2010; Steele & Aronson, 1995; cf. Fraser & McLoughlin, 2018).

In summary, an expanded vocabulary needs to be developed so that teachers have more nuanced tools with which to diagnose the individual learner's barriers to learning and devise appropriate interventions to support learners in overcoming these barriers. It is beyond the scope of this study to quantify the full range of barriers to learning that may occur for learners through disability, challenging social environments or other factors, but knowledge of this area of research is noted as essential for teachers as they facilitate the advancement of learners towards higher levels of expertise in specific knowledge domains.

Thirdly, a new language to systematically describe alternative methods for reorganising the curriculum in alignment with CLT has not yet been developed. For example, since CLT focuses on advancing learners towards higher levels of expertise in specific knowledge domains, it is suggested that the curriculum be structured around the organising principle of "nodes of expertise", a term introduced in this study as a useful placeholder and adopted to describe targeted learning interventions in response to diagnosing barriers to learning.

The concept of a node of expertise may be inferred from educational literature. For example, Davies (2006, p. 1) suggests a possible format for arranging curriculum according to threshold concepts; these include "ways of thinking and practicing", "exposing the ground rules" of a specific knowledge domain (Sheeran & Barnes, 1991) or epistemes (Perkins, 2006). The concept implies a scale of measurement of expert attainment against which the nodes or clusters of expertise-derived knowledge may be measured. Dreyfus & Dreyfus (1980) have contributed such a model of expertise to clarify the stages of expertise development, with five delineated stages:

1. Novice
2. Advanced beginner
3. Competent
4. Proficient
5. Expert.

Benner (1982) provides an example of an implementation of the Dreyfus and Dreyfus model in nursing education, thereby providing a practical example of how a curriculum based on expertise may be evaluated.

In the current study an expanded version of the Dreyfus and Dreyfus (1980) model is proposed with more detailed stages for attaining expertise by defining learner levels as:

1. Pre-novice
2. Novice
3. Advanced beginner

4. Competent
5. Proficient
6. Mastery
7. Expertise.

As CLT is a theoretical framework derived from a model of expertise that has been validated across a range of learning environments, it is suggested that an expanded scale of expertise that includes the full range of learner levels would support the increased pedagogical application. For example, teachers may provide information about these levels to learners as a prompt or cue to reflect on their progress towards expertise within a discipline. This model suggests that learners who are diagnosed to be within the first three levels (pre-novice, novice and advanced beginner) will require the highest levels of scaffolded support through CLT teaching strategies including worked examples, goal-free problems, use of the modality effect and removal of redundancy from learning environments and materials (Kirschner, Sweller & Clark, 2006). Chapter 10 and Appendix F provide a range of diagnostic tools developed in this study to support the implementation of CLT effects using the pedagogical model of designing and implementing nodes of expertise (NOE) which are proposed as an alternative model for curriculum development (Appendix F). In this model, NOE represent clusters of domain-specific core knowledge that learners are required to understand and which are designed as follows:

1. informed by expert practitioners e.g. through techniques of cognitive task analysis (CTA)(Clark, Feldon, van Merriënboer, Yates & Early, 2008) so that the curriculum extends beyond content knowledge to its application of both knowledge and underpinning thought processes and situation awareness (Endsley, 1988) in authentic contexts. NOE are clusters of knowledge and skills that learners require to advance to the next level of expertise. NOE also

draw on the knowledge experts in varied, authentic contexts of application that has been deconstructed for instructional purposes

2. incrementally formatted steps of knowledge that leads learners from simple to increasingly complex content and application

3. conceptually linked domain knowledge in terms of understanding its meaning and relevance within its own discipline, its relation to other disciplines and connected to the prior knowledge and future learning aspirations of learners.

A curriculum that is organised in NOE focuses on clusters of learning (facts, concepts, processes, procedures or principles) that may be divided into declarative (facts) and procedural (how-to) categories of knowledge (Sweller, Ayres, & Kalyuga, 2011), as well as the more implicit functions of how experts in specific knowledge domains apply this knowledge. The aim of separating declarative and procedural knowledge at the learning design stage is for learners to automate the recurrent, core knowledge and derived rules of the discipline and ensure that cognitive overload does not occur and contravene the narrow limits of change principle.

The salient point about a curriculum designed in this way is that learners can progress along an individual pathway towards expertise within a flexible time frame (Bloom, 1968), with teachers being aware of the variations in time–to–mastery for different learners. The expertise model of learning therefore aligns the curriculum with the underpinning principles of CLT; for example, the narrow limits of change principle supports time flexibility for schema formation and automation by novices. This is due to slow formation and automation requiring extended timeframes by definition. This principle also affirms the validity of a mastery model of learning, where the progress of learners is evaluated according to individual and personalised pathway of progress to increasingly higher levels of expertise within a specific knowledge domain i.e. replacing a norm-referenced teaching model with a criterion-referenced model.

As noted, NOE focus on recurrent procedural knowledge with the goal of ensuring learners form and automate schemas in the core knowledge of the particular knowledge domain. For example, the structure of an essay will need to be learned as distinct from the knowledge that will be contained within the structure of the essay. The strategy of separating declarative and procedural knowledge may lower cognitive load by having fewer interacting elements i.e. learners first form and automate the recurrent, structural elements within long-term memory, a process which releases capacity in working memory. For example, when learners are required to draw on this prior knowledge to write an essay, the structure which has been automated can be used as a LTWM element without imposing additional load on working memory. This means full attention and working memory capacity can be dedicated to populating the pre-learned structure with content.

NOE may also point to the need for curriculum development to have greater alignment between the learner's prior knowledge, heutagogical capabilities, interests, motivations and vocational aspirations, since these parameters also comprise the prior knowledge of learners. The proposed framework therefore suggests a focus on early access to learning the skills and knowledge used by experts; in addition, it advocates for personalising learning by considering additional dimensions of the learner's persona.

A NOE should be developed holistically and may be formatted as a small learning episode, a larger cluster of concepts or an incrementally formulated set of processes or procedures (cf. Bruner, 1960–Spiral curriculum). A NOE also requires explicitly stated relevance and purpose and should be related to the application of knowledge in authentic workplace contexts. In addition NOEs require clear links to the learning experiences that will follow.

A NOE should also include the opportunity for learners to engage in deliberate, varied practice of core concepts or content in order to support learners in transferring knowledge to new tasks or problems. In terms of schema theory, separate schemas are formed for the individual components that make up the entire NOE and are then rehearsed until multiple elements become integrated into a single schema. A NOE may therefore be defined as an interrelated group of schemas that have been integrated into a single element through deliberate, persistent practice. This is probably the most critical factor in applying CLT pedagogically. The automation of schemas releases processing capacity in working memory. Truncating the learning process by placing an emphasis on the coverage of large volumes of content under time-pressured conditions and neglecting the formation and automating of schemas results in cognitive overload, loss of expert application of knowledge and potential impact on affective areas such as learner motivation and morale. Moreover, since automated schemas occupy a very low working memory resources, lack of schema automation as a pedagogical focus misses the opportunity for learners to benefit from one of the most powerful mechanisms in human cognitive architecture: LTWM (Ericsson and Kintsch, 1995). The organisation principle of NOE in curriculum design implies the removal of redundant knowledge that does not support the direct acquisition of expertise by learners. While it may be time-consuming to structure the curriculum according to NOE, nodes may be shared using a technological architecture and standards, where teachers can use an online repository to distribute and share a database of validated nodes of expertise. Additional research is required to develop this framework further.

A final area of CLT that may require further definition in order to be useful to educational practitioners is the incorporation of additional states that are relevant to pedagogical application of CLT principles for automating schemas. The elaborated pedagogical cycle is suggested in Table 5.3.

Table 5.3 An expanded view of steps to schema automation within a CLT framework

Stage	Description
Formation	The introduction of the NOE to the learner; presentation of the subject area demonstrating its internal logic and connectedness, its meaning and relevance to the learner's aspirations as well as the broader subject area as practised and applied by experts. For example, does the NOE consist of facts, concepts, processes, procedures or principles? Does the material constitute high element interactivity for novice learners, requiring deep understanding, or is there low element interactivity consisting of disparate facts? What heutagogical skills are required for the formation of the NOE?
Validation	Validation is the stage where teachers either confirm or diagnose issues with the levels of schema construction of learners (absent, incomplete, erroneous, or automated for near or far transfer – see Section 5.8.4) to adapt learning appropriately to their individual needs. In addition, it is the stage where teachers diagnose issues with barriers to learning (knowledge or understanding, affective factors, or heutagogical factors) To facilitate validation, learners need to do activities to reflect their understanding by means of external expression (verbal feedback, self-explanation, visual representation, teaching a peer, doing a presentation for peer review); the teacher identifies and modifies or corrects this understanding; the teacher models or provides examples of how experts think about the subject and solve problems (Acharya & Shukla, 2012)(cf. Sweller, Ayres & Kalyuga, 2011, p. 228–Mirror Neurons).
Automation	Validation continues to occur as learners engage in deliberate practice over extended time periods to automate schemas. At any point, the teacher may validate schemas or diagnose issues with levels of prior knowledge or barriers to learning. In the first stage of automation, the aim is for teachers to assist learners in using worked examples to establish the procedural steps and the thinking processes required by the NOE. The learner practices with goal-free problems and worked examples, faded examples (or completion problems) and then traditional, unscaffolded problems to establish the correct procedures and associated thinking processes. Examples are structured to avoid the learner engaging in means–ends analysis which is resource-heavy in working memory but has weak support for changes to long-term memory.

Application (near transfer)	At the near transfer level, the process learned in the previous level is applied to situations or problems with similar surface features. Rote practice is only done to validate processes, while validation of understanding may occur as part of this process by teachers using cueing. When learners have demonstrated capability in applying learned knowledge to near transfer tasks, additional NOE can be devised to enable learners to understand how to apply the knowledge in far transfer contexts.
Application (far transfer)	When processes have been validated and the teacher is satisfied that learners have learned to execute NOE fluently, learners are introduced to applications of the process in varied (anisomorphic) contexts. Validation needs to occur for teachers to modify or correct the thinking processes of learners and to explain or model how experts think in applying the processes. Teachers may use cueing to explain direct and explicit connections between known and unknown concepts or principles.
Application (authentic contexts)	At this level, automation of knowledge application in authentic, complex contexts occurs, with flexibility of thinking and a high level of situation awareness i.e. the expert application of knowledge, processes, procedures and principles to complex and unpredictable problem environments. These situations may include high-risk environments or simulated high-risk environments where situation awareness and rapid responses are required and where self-management of cognitive load balancing may need to occur. Situations may include aircraft flight training, air traffic control operations, medical emergency treatment environments and disaster or emergency relief operations.

In summary, the expanded definition of possible stages of automation articulates the pedagogical processes that support higher levels of adaptivity of learning to the needs of learners. Teachers who have a more granular knowledge of these stages as expressed in Table 5.3, may be empowered to direct learning interventions more specifically. In essence, this process reflects the translation, or transposition, of CLT principles and effects into a more detailed format, demonstrating the "how-to" procedures for introducing CLT in the classroom. Appendix F provides examples of additional tools for supporting teachers in the more comprehensive analysis of learner schemas through Diagnostic Conversations (DCs), identifying specific barriers to learning and formation of NOE.

5.9 Implications for the study

The criticisms and critiques of CLT noted in this study have been derived from two key sources: first, peer reviewed literature and secondly, areas that are pertinent to the study as observed by the researcher. These criticisms and critiques do not impact the primary purpose of this study, which is to use the unified model of human cognitive architecture and effects arising from RCT experiments within CLT research for informing the design of CLEMS.

As outlined in Chapter 4, the historical research into cognition established the foundation for the CLT model which provides a deeper understanding of working memory limitations, processes of schema formation and automation. This model therefore reflects a cognitively-based rationale for focusing pedagogy on the direct acquisition of domain-specific knowledge.

Valid criticisms arising in the peer reviewed literature provide impetus for ongoing research in order to clarify issues related to the methodological and scientific basis of CLT and continue the pursuit of objective cognitive load measurement. These criticisms do not undermine the core capacities, functions and interrelationships between memory systems during learning as articulated within the CLT model. In addition, the self-reflective nature of the CLT community of researchers ensures that understanding of these processes is continually refined in order to generate pedagogical applications of CLT that increasingly align with the structure and functions of human cognitive architecture. For example, a dominant approach used within CLT is to seek alternative theoretical explanations for identified effects (Sweller, Ayres & Kalyuga, 2011).

Sweller (2006) notes three directions being pursued in CLT research since the early 2000s. First, the investigation of measurement devices to determine the nature of learning materials that should be provided to learners. Secondly, the investigation of the effect of asking learners to imagine concepts or procedures; this has been followed up in the intervening years through validation of the imagination effect (Sweller, Ayres & Kalyuga, 2011). Thirdly, the use of instructional findings to deepen our understanding of human cognition with reference to evolutionary factors.

The current study has been based on the first of the three above-mentioned research directions, namely the investigation of measurement devices to determine the nature of learning materials that should be provided to learners (cf. Aldekhyl, Cavalcanti & Naismith, 2018). The suitability of this direction for this study is due to the fact that the effects and strategies arising from CLT between 1988 and 2003 lend themselves to being collated into an instrument such as CLEMS.

It has emerged through this study that continued research is required regarding the application of CLT effects and strategies and some critiques have been presented in this chapter. An obvious risk in applying CLT effects and strategies in practice is that this may not be done systematically since CLT is a complex system of interrelated effects that are intertwined with the level of complexity of learning materials and the learner's prior knowledge. Using a simplistic approach such as implementing a single strategy is likely to have limited benefits at best, or possibly negative effects if the learner's prior knowledge is not factored into the learning design. For this reason the focus of this study is to synthesise the effects and strategies that have arisen from CLT within a technological system (CLEMS) that enables educators to apply CLT strategies systematically and holistically. CLEMS facilitates the evaluation of the impact of applied strategies in terms of learner outcomes as well as the theoretical assumptions underpinning strategies. It is suggested that without this dual-level evaluation process it would be extremely challenging for educators to test the assumptions underpinning learning design or to articulate connections between strategies and outcomes. As research into the measurement of cognitive loads continues to develop (Appendix G) and new effects become validated, it is important that CLEMS has the flexibility to expand to accommodate them, for example the capability of determining types of cognitive load more accurately. The history of CLT has been characterised by experiments to measure cognitive loads both subjectively and objectively (Sweller, 2018a, 2018b) and the most effective indicator of cognitive load to date is its subjective measurement using the Paas scale of cognitive load measurement. Due to its ease of use it minimises interference within the learning process (Sweller, Ayres & Kalyuga, 2011).

Researchers have also investigated measuring other categories of load, and the most significant studies in this direction have been collated by Zheng (2018). The complexity of the cognitive load construct, which has multiple variables (including three attributed loads, prior knowledge and motivation of the learner), necessarily implies that precise measurement may not be at all possible due to the unknown variable of the learner's prior knowledge. A recommended research direction for the measurement of cognitive load includes advanced scanning technologies that measure brain activity functions (de Jong, 2010) during learning. Zheng (2018) (see Appendix G) has provided a collation of the research related to the subjective and objective measurement of cognitive loads in his book, *Cognitive Load Measurement and Application: A Theoretical Framework for Meaningful Research and Practice*. This overview represents the measurement of cognitive loads as a dynamically growing research discipline centered in the field of physiological and neuroergonomic metrics (Baldwin & Cisler, 2018). Experimental initiatives and endeavours include secondary task experiments (Park & Brünken, 2018), electroencephalography (Antonenko & Keil, 2018) and ocular-motor measures (Cook, Wei & Preziosi, 2018).

While it is not possible to include objective measures of cognitive load into CLEMS at this stage, CLT research provides a broad range of useable and useful findings for incorporation into CLEMS to support educators in the implementation, management and evaluation of CLT strategies in practice.

5.10 Summary

In this chapter, the unified model of CLT was reviewed, the five underpinning principles on which the model is based were discussed and the suite of effects and strategies for applying CLT in practice were outlined. Criticisms of CLT within the literature were discussed as well as an additional critique of CLT in terms of advancing its systematic application within educational environments. This additional critique included the need for more specified definitions of prior knowledge of learners, the requirement for an expanded model of stages of expertise, and a broadened range of stages of schema development.

This chapter defined the core knowledge of CLT in terms of the suite of pedagogical strategies and guidelines for inclusion in CLEMS and discussed the current lack of objective measures of cognitive load. In preparation for advancing to the next stage of development of CLEMS, Chapter 6 presents the conceptual framework (CF) of the study. The CF provides an ontological rationale for synthesising all the research to this point into a blueprint for CLEMS that encapsulates the CLT knowledge base as an evaluation standard.

Chapter 6 – Conceptual Framework

6.1 What is a conceptual framework?

The conceptual framework (CF) presents a global view of the study and is a continuation of the literature review and previous chapter. Ravitch and Riggan (2017) assert that the CF represents a method of linking together all of the critical elements of the research process. These elements include the researcher's approach to, and interest in, the problem being addressed, the themes arising from the literature, and the interconnected theoretical frameworks and methods of which the study is comprised (Farmer, 2007; cf. Holweg & Van Donk, 2009; see also Jabareen, 2009b–Building a conceptual framework).

Maxwell (2005, p. 39-40) expands this definition by listing the key functions and purposes of the CF synthesised into a framework or blueprint. Miles and Huberman (1994, p. 440) also consider CFs as models for articulating "key factors, constructs, or variables, and [the] presumed relationships among them".

Based on these definitions, the usefulness of the CF in this study is pivotal; a sense-making process applied to the broad range of themes, concepts and approaches to education identified in the literature review. Moreover, the CF provides a lens through which the issues under investigation may be viewed in order to determine the most feasible direction for the study. Effectively, the CF has the goal of presenting the reviewed base of research as a cohesive framework to serve as a model (Maxwell, 2005) for carrying out the study. In this way, the CF serves as a catalyst for addressing the research question and, in the case of the current study, inform the development of CLEMS through the use of two key concepts or themes: synthesis and emergence.

6.1.1 Applying themes of synthesis and emergence in the study

The overarching themes of synthesis and emergence have been used for guiding the formation of the CF of this study (Bakker, 2014; Mueller, 1958; Pawson, Greenhalgh, Harvey & Walshe, 2004; Ueda, 2001) with the goal of "the development of new concepts" (Kryssanov, Tamaki & Kitamura, 2001, p.1), or "developing knowledge" (Koshy, 2005).

To this point in the study, the themes of synthesis and emergence have been nuanced in the approach used to analyse the literature review and distill the key findings into a framework for advancing the enquiry of the study. Numerous themes have been identified related to the evaluation of the quality of learning design. To continue advancing the study towards its goal, these themes require synthesis into a theoretical model which may then serve as the basis of the specification for CLEMS. Using a design-based research (DBR) methodological approach the model will be transformed through three research iterations from a theoretical construct into a software prototype.

This section describes how the themes of synthesis and emergence have been applied in the study to this point, and how they propel the study to its next stage of development.

Key themes emerged from the literature review (theoretical framework) by investigating issues surrounding the problem of evaluating the quality of learning design. This investigation reviewed four dominant paradigmatic perspectives of education, from which cognitive research emerged as a suitable paradigm for informing the design of CLEMS due to its grounding in empirical research with resulting cohesive theories and models of learning (cf. Gage, 1989–Paradigm wars; Guba, 1990).

After the four main educational paradigms provided a general background to educational research, a review of approaches to the design–teaching–learning–evaluation process was conducted. The identified approaches resulting from this review were organised into a taxonomical classification of 19 categories. Criteria for evaluating the relative quality of these approaches were adopted from scales used in evidence-based medical research, an approach that aligns with the goals of the evidence-based practice movement in education.

The goal of this process was to derive a standard for evaluating approaches to the design–teaching–learning–evaluation cycle in terms of their relative levels of quality. This aligns with the raison d'être of this study, expressed as a need to have strategies for strengthening learning that are consistent and reliable; moreover, these strategies require robust explanations of the underpinning mechanisms of learning from which they have been derived, as well as the specific conditions or constraints under which they operate with greater or lesser efficiency. This requirement represents a theory–practice link between the strategies and their cognitive mechanisms; CLT has been identified as fulfilling these requirements and therefore represents a suitable basis for the purposes of the study.

This standard was identified in Chapter 1, using the Cochrane Collaboration (Cochrane, 1979; Grimshaw, 2004; Higgins & Green, 2011) and Campbell Collaboration (2019) to synthesise a scale for organising educational research into relative levels of robustness and reliability. The contributing factors to this standard included strategies arising from RCTs, underpinned by a unified model of cognition. As affirmed by Schneider, Carnoy, Kilpatrick, Schmidt and Shavelson (2007, p. 11, 36):

> When correctly implemented, the randomized controlled experiment is the most powerful design for detecting treatment effects. The random assignment of participants to treatment conditions assures that treatment group assignment is independent of the treatment characteristics of group members; thus differences between groups can be attributed to treatment effects rather than to the pretreatment characteristics. Randomized experiments, however, indicate only whether there are treatment effects and the magnitude of those effects; they do not identify the mechanisms (i.e. the specific aspects of the treatments in question or of the settings in which they are implemented) that may be contributing to such effects. In terms of validating the mechanisms,

> randomized experiments can be used in conjunction with other methods to examine the mechanisms that help explain causes.

The method used to "examine the mechanisms that helps explain causes" (Schneider, Carnoy, Kilpatrick, Schmidt & Shavelson, 2007, p. 11, 36) in this study is adopted from the unified CLT model of human cognitive architecture. The literature review identified CLT as presenting a unified model that explained the underpinning mechanisms of learning in terms of human cognitive architecture (Newell, 1990; Sweller, Ayres & Kalyuga, 2011). In addition, CLT research had the advantage of having contributed a suite of specific strategies based on RCTs that lend themselves to forming an evaluation standard suitable for the requirements of the new learning design quality evaluation instrument. Specifically, the application of a filtering process using the two identified criteria:

1. derived from RCTs
2. based on a unified model of cognition.

The results of this filtering process identified CLT research as providing a suitable base to serve as a standard for evaluating the quality of learning design.

The research question arising from the identification of CLT as a suitable evaluation standard was expressed as: "How can the research arising from cognitive load theory inform the development of a new eLearning design evaluation instrument that is useful to educational practitioners?" The purpose of the conceptual framework is therefore to provide a blueprint or set of guidelines for informing the design of the new evaluation instrument in terms in response to the three key areas expressed in the research question:

A. How can the research arising from Cognitive Load Theory

B. be used to inform the development of a learning design evaluation instrument

C. that is useful to educational practitioners?

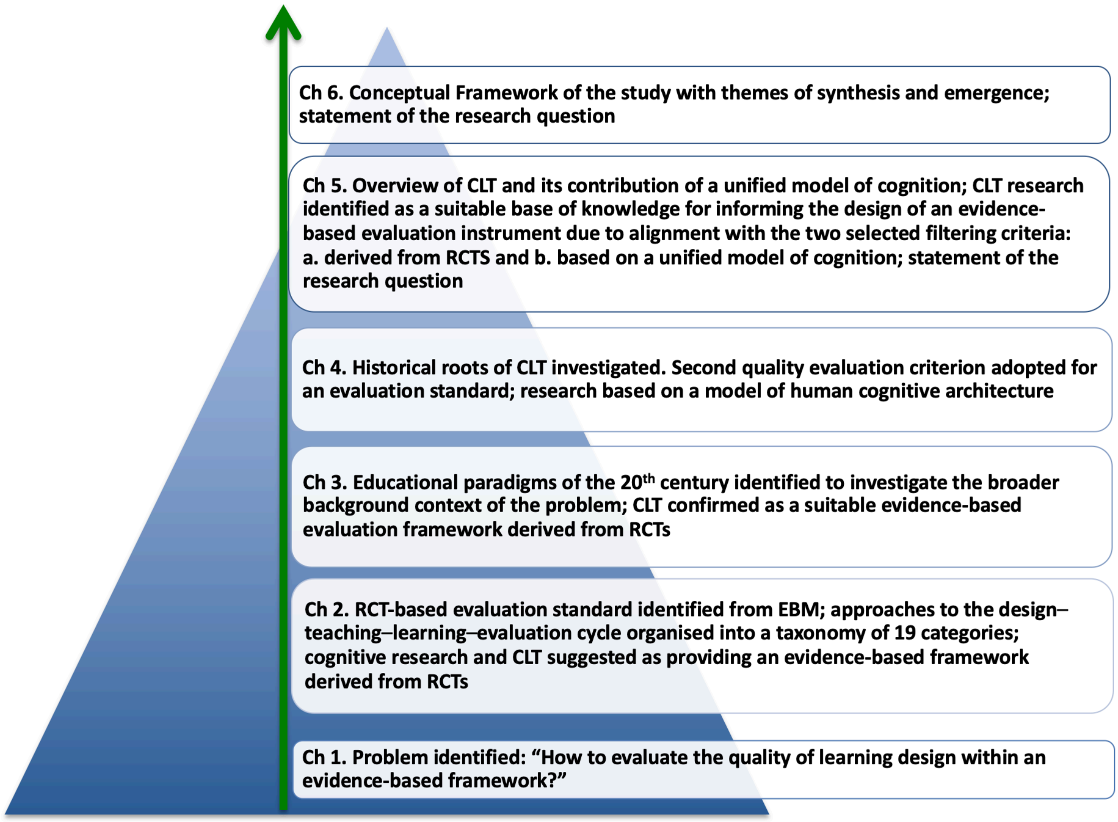


Figure 6.1 Summary of the developement of the study to this point

6.2 Macro and micro functions of the conceptual framework in the study

The CF serves as a framework that encapsulates the key ideas to be studied (Miles & Huberman, 1994). This occurs at two levels within a study as it brings cohesiveness to the identified themes. First, it functions at a macro level, where it represents the broader, structural components of the study paradigm that includes the following foci (Crotty, 1998; de Gialdino, 2009; Kivunja & Kuyini, 2017; Macintosh, 2008; Scotland, 2012):

1. Ontology

2. Epistemology

3. Theoretical framework (literature review)

4. Methodology

5. Research methods.

Secondly, the CF functions at a micro level, where it specifies the principles by which themes and ideas are linked into a cohesive framework that advances the study towards its goal in addressing the research question. The framework functions therefore support the process of organising, linking, clarifying and accommodating identified themes within increasingly coherent structures (Attridge-Stirlings, 2001; Maxwell, 2005; Seel, 2017).

6.3 The purpose of the framework functions in this study

The research question provided a focus for the development of the framework functions, which Ravitch and Riggan (2017, p. 5) define as: "an argument about why the topic one wishes to study matters, and why the means proposed to study it are appropriate and rigorous [and are] a series of sequenced, logical propositions, the purpose of which is to ground the study and convince readers of the study's importance and rigor by arguing convincingly" in key areas, as follows:

a. how the research question reflects the relevance of the study
b. how the research design aligns with the research question, the goals of the study, and research context
c. how the data arising from the study provides raw material that is sufficient to investigate the research question
d. how the analytic approach adopted by the researcher allows questions to be addressed effectively (Ravitch & Riggan, 2017, p. 5).

Miles, Huberman and Saldanha (2014, p. 20) elaborate on the function of the framework functions as follows:

> A conceptual framework explains, either graphically or in narrative form,
> the main things to be studied – the key factors, variables, or constructs –

> and the presumed relationships among them. Frameworks can be simple or elaborate, common-sensical or theory driven, descriptive or casual … conceptual frameworks are developed at the beginning of a study and evolve as the study progresses.

The set of figures in this chapter provide graphic representations that illustrate conceptual links between key components of the study in order to advance the theoretical model of CLEMS towards its development into a useable software artefact. In this way, the functions and characteristics of CLEMS identified from themes in the literature review will be distilled and formulated through appropriate methodology and methods, thus representing the emergent concepts contained within CLEMS.

Maxwell (2005) emphasises the systemic nature of the framework functions by suggesting that the study's CF, which represents a system of assumptions, concepts, beliefs, expectations and theories that inform and support the research enquiry, forms a critical part of the design. He continues by asserting that the uniqueness of frameworks functions "as something that one constructs, not something that is found" (Maxwell, 2013, p. 95). He asserts that ideas and concepts incorporated into the framework functions are borrowed from elsewhere, but the structure, the overall coherence, is developed with reference to a specific study, not something that exists in ready-made format. This view aligns with the eclectic nature of the framework functions for the current study as a uniquely developed construct that links disparate areas of knowledge together to form a progressively refined framework in which the research question can be addressed.

Besides serving as a guide for carrying out the study, the purpose of the framework functions has also been noted to transcend the immediate methodological processes of the study to informing practice and policy, as well as contributing new knowledge to the discipline. Marshall and Rossman (2011) suggest that the framework functions consist of three primary elements:

- First, the focus is to convince readers that the study is significant and worthwhile and entails building an argument that connects one's research to a range of issues: key theories; theoretical perspectives; policy issues; problems of practice; or social and political issues and realities that affect people's lives and society in general. This point aligns with the particular problem that the research addresses, in this case the quality of learning design
- Secondly, the framework functions reflect the key intellectual traditions that serve as a guide for conducting study as identified through a careful and thorough literature review related to the topic. This point aligns with the themes identified in the literature review that represent the body of accumulated knowledge regarding the process of teaching and learning within the discipline of education
- Thirdly, a CF functions to identify the gaps in what is known by a. providing a framework for the analysis and critique of previous research b. by extending, modifying or developing existing theory or c. by identifying practices and policies that appear not to be working. This aligns with the interpretation of the literature review in order to identify a research gap, with the aim of addressing it through the research question.

Marshall and Rossman (2011, p. 58) propose that the above three elements “constitute the building blocks for a framework functions and help refine important and workable research questions”. These three building blocks align with the broad processes adopted to shape this study by highlighting the significance of the problem, drawing on the intellectual traditions in education in which the problem is situated and setting in motion the processes for addressing the problem.

By placing all of these identified ideas in close proximity and defining links between them, the shape of the study and its goal, the conditions for the emergence of CLEMS may emerge, thus expressing the overall conceptual framework of the study as synthesis and emergence.

6.4 The ontological perspective of the study

As observed by Maxwell (2005) and Ravitch and Riggan (2017), the CF is formed on a foundation of underpinning assumptions. These are expressed through the ontology and epistemology that constitute the broader frameworks of the research (Jabareen, 2009a, 2009b). Ontology is a philosophical term that defines "what exists" and is the broadest framework of the study, as it articulates the assumptions underpinning the study; building on the ontology, the epistemology deals with 'the nature of knowledge, its possibility, scope and general basis" (Hamlyn, 1990, p. 10; Jabareen, 2009a, 2009b; Macintosh, 2008).

The design of the entire study will be situated within these two frameworks, and they are now articulated in order to establish the principles that guide the trajectory of the research.

6.5 Ontology

6.5.1 Ontological framework of the study

Ontology is derived from two Greek works, onto (existence, or being real) and logia (a science, or study). Lofgren (2013) differentiates between ontological perspectives in different contexts and domains, for example philosophical and non-philosophical contexts. This broad definition is supported by Smith (2008), who views ontologies as variable in terms of the purpose of the studies they support. In terms of pure philosophy, ontology takes a broad perspective that attempts to identify the basic components of the existing world, what is perceived as real, to the "state of being" (Busse, et al., 2015). Moreover, philosophical ontology also attempts to define the relationship between components that are perceived as real (Guarino, Oberle & Staab, 2009). The broad range of interpretations regarding ontology include the following:

- Formal Ontology is the scientific endeavour that focuses on the ordered and systematic development of interrelated, axiomatic theories that describe modes, forms and views of the essential nature of being using a structure consisting of different levels of granularity and abstraction (Herre, Heller, Burek & Hoehndorf, 2006)
- Ontologies can be expressed as formal specifications of a shared, conceptualised idea (Guba, 1990; Guba & Lincoln, 1994)
- Ontologies may include rationalisations for the use of technologies (Herre et al., 2006, p. 1).

The importance of ontological frameworks within disciplines of study has been recognised in fields as diverse as e-commerce, geographic information science, and intelligent information access. In each of these fields a common ontology is needed in order to provide a unifying framework of enquiry (Herre, et.al., 2006).

The above definitions represent ontologies in both abstract (concepts) and concrete (technologies) terms. The type of questions raised within philosophical ontologies concerns the relative "realness" of physical items compared with abstract concepts. For example, is a learner more real than the concept of education, and what is the nature of the relationship between them? The reason that this type of philosophical discourse is important is because it can be used to construct models, theories and hypotheses that provide a better understanding of the ontological nature of the social and scientific world and their interrelationships (Archer, Sharp, Stones & Woodiwiss, 1999; Bhaskar, 2008; Poole, Smyth & Sharma, 2009).

Ontological questions provide holistic frameworks for understanding complex social and scientific entities and generate advances in understanding through different types of questions.

Ontological questions may be causal i.e. with the purpose of determining causative links between things or events e.g. “did condition/event a cause condition/event b to occur? Alternatively, these questions may be generative, asking, “under what conditions could condition/event a cause condition b to occur?” Ontological understanding of reality and being may discover links between entities and events and may use this knowledge to improve technical processes, conditions, or society in general (Bhaskar & Danermark, 2006; Munir & Anjum, 2018).

Educational ontology seeks to define the parts and processes occurring within particular educational contexts. These parts and processes, or mechanisms, may occur at multiple levels including external levels such as institutional structures, curriculum, or relationships within the learning environment e.g. relationship between teacher–student, student–student or between students within collaborative environments (Tuovinen, 2000). Additionally, the quest for an understanding of the processes underpinning learning extends to the unobservable cognitive mechanisms of working memory and long-term memory within the CLT model of human cognitive architecture (cf. Ambrose, Bridges, DiPietro, Lovett & Norman, 2010–How learning works; Sweller, Ayres & Kalyuga, 2011).

Ontology is therefore important to the current study as it identifies “what is” within the context of the study so that new knowledge of “what might be” can be generated.

Within the current study, Critical Realism (CR) presents an ontological framework for accommodating the emerging themes from the literature review at a macro level, as well as the multi-mechanistic functions of memory systems identified within CLT at a micro level. While pragmatism presents a “flat”, single-focused approach to solutions, the CR model provides placeholders for accommodating this complex range of factors, as well as a vocabulary for defining them (Ayers, 2011; cf. Shipway, 2005). The need for a vocabulary to express the complex ideas that have emerged from the literature review has been a key factor in determining the appropriateness of CR as an underpinning ontological framework for the current study (Biesta & Burbles, 2003; Clark, 2008; cf. De Souza, 2018–Educational change in Singapore; cf. Kalolo, 2015–Pragmatism in education).

CR originated with the philosopher Roy Bhaskar (2008, 1993, 1998) during the 1970s and is a "meta-theoretical perspective" (Fleetwood, 2014). It integrates two philosophies; first, a philosophy of science termed transcendental realism (Bhaskar, 2008; Clark, 2008) and secondly, a philosophy of social science termed critical naturalism (Bhaskar, 2008) to describe a multi-layered and multi-mechanistic reality that explains both natural and social worlds (Bhaskar, 2008). CR postulates that social phenomena have intrinsic meaning and these meanings must be understood, not necessarily measured or counted as within positivism. CR also provides a vocabulary set for defining levels of meaning and interactions between underpinning causative mechanisms that may not be visible or even recognised by observers, but which exert an impact on social environments e.g. learning environments. Since CR seeks to identify and understand underpinning mechanisms that give rise to social phenomena, it differs at a foundational level from constructionist paradigms by asserting that reality is knowable (Easton, 2010).

Bhaskar's (2016, p. 82) ontology explains the social world as "emergent, concept and activity dependent, value-drenched and politically contested part of the natural world" (Bhaskar, 2016, p. 82; see also David, 1971; see also Edwards, Mahoney & Vincent, 2014, p. ix). Social phenomena are therefore embodiments of interactions (both co-operative and counteractive) that occur between observable and unobservable mechanisms (Fleetwood, 2013, 2014; cf. Shaw & DeForge, 2012).

Bhaskar (1998) states that the characteristics of social structures determine the manifestation of social phenomena. This implies that the nature of social enquiry and the capability of social reality both require scrutiny. The key difference between CR and an ontology based on scientific positivism is that positivism seeks to prove phenomena through the use of empirically-validated, quantitative methods. CR, however, looks beyond observable phenomena to the underpinning mechanisms and poses the question: "What should reality look like for science to be possible?" (Bhaskar, 1998, 2008). CR therefore opposes a reductionist view of reality in which different levels are "collapsed" together and interpreted in an oversimplified way. By doing so, CR proposes the investigation of the stratified underpinning layers and mechanisms that constitute reality. This aspect of CR is most relevant to the current study, which implies the adoption of a model of cognition within teaching environments as a necessary sub-stratum for explaining learning, as opposed to rejecting a more detailed explanation of cognitive mechanisms, for example as espoused within constructivist approaches. CR therefore represents a framework that accommodates CLT multi-layered view of learning mechanisms within human cognitive architecture i.e. the view of the learning process through an analytical lens that examines the structure and functions of sub-systems within cognition that occur during learning.

CR postulates a view of reality underpinned by two assumptions:

1. reality exists independently of human perception of it, which aligns with the positivist viewpoint; however, it extends positivism by acknowledging that entities that comprise independent reality have governing powers, qualities and structures (Sayer, 2000, p. 11)
2. CR assumes that reality consists of multiple levels of internal structures or layers (called laminations) as well as multiple interactive mechanisms, referred to by some theorists as multimechanismicity (Archer, Bhaskar, Collier, Lawson, & Norrie, 1998; Easton, 2010; Emamjome, 2018; Fay, 1990; Tsang & Liu, 2016) or as used in this study, multimechanistic.

It is the interaction between multiple layers of reality that gives rise to new information, thus providing a rational link between the ontological framework and the epistemological origins of knowledge (Wikgren, 2004). In the context of this study, a model of learning has been identified that accounts for both pedagogical practices and their underpinning generative mechanisms. In terms of CR, it is the interaction of multiple mechanisms including sensory input, cognitive loads, working memory, long-term memory and the construct of chunking that give rise to, or impact, the resultant level of schema formation and automation. The explanation of interactions between mechanisms in CR also echoes the dialectic thesis–antithesis–synthesis model postulated by Socrates initially, and later by Hegel (1807/1949); in this construct, thesis and antithesis are interacting mechanisms that give rise to new – synthesised – knowledge (Popper, 1959). While the dialectic model expresses the process of emergence at a macro level, CR provides a new vocabulary set for defining it at both macro and micro levels (see also Galston, 1982–Dialectic).

CR therefore underpins the ontological, epistemological and methodological perspectives of this study as it provides a framework in which the identified complexities associated with learning and teaching can be explained through the metaphor of multiple levels and multiple interacting mechanisms. This is due to CR providing a language (Sandoval, 2004) set to define the multiple levels of meaning and mechanisms portrayed through a plethora of learning theories (Anderson & Shiffrin, 1980; Phillips, McNaught & Kennedy, 2010; Wheeler, 2018).

In CR the multi-layered nature of reality is expressed in terms of the “real”, the “actual” and the “empirical” (Sayer, 2000). First, real is defined as existing structures, whether natural or social, regardless of their status, as empirical objects, and regardless of our understanding of them. Real also includes the powers and internal structures of these objects, whether social (such as government) or physical (such as base metals) (Bhaskar, 1998, 2008; Sayer, 2000). The multi-layered model is based on the assumption that real things have causal powers and structures, as well as capacities and potentials to behave in certain ways, and propensities or capacities for certain types of change. Although the real is not always understood or fully actualised, it exists with all its complexities and potentials as objective entities. As an example, an institution may have internal processes for enrolling students or for students to pay fees online. These processes may or may not be activated, but they and their capabilities exist regardless of anyone's engagement with them or even their knowledge of these processes. Alternatively, a university may have the infrastructure (real capability) for supporting students at a personalised level, but the actual situation might be a very low level of engagement between students and these support facilities.

The principle of the real is also illustrated through the CLT model of human cognitive architecture. The cognitive mechanisms underpinning learning, including working memory and long-term memory, took almost a century of research to be defined (Chapters 2-4); however, while these mechanisms existed in their entirety as real, they were only progressively understood through ongoing empirical research, with CLT validating these mechanisms through RCTs and providing a unified model for explaining the interactions between these mechanisms holistically.

In contrast with the real, the actual refers to events that are generated through interactions between real mechanisms. In nature, the difference between real and actual may be illustrated by comparing rainfall and its generative mechanisms. Rainfall occurs as an actual event in nature, but underpinning this event are the causative mechanisms of precipitation. Bhaskar (1998, 2008; Bhaskar & Danermark, 2006) distinguishes between the real, which is comprised of entities with generative mechanisms, and the actual composed of the resultant event. The notion of the actual aligns with the CLT model of human cognitive architecture. Novice learners who are present in formal learning environments will have their real generative learning potential activated to various levels of actualisation depending on the alignment of teaching strategies with the functions of cognitive architecture. In this model, CLT provides the tools for releasing the potential of the real in learning through the alignment of learning design with the structures and functions of human cognitive architecture; moreover CLT provides a suite of strategies that may be used to design learning interventions that optimise the engagement of the real underpinning mechanisms of working memory and long-term memory. Finally, empirical is defined as "the domain of experience, and insofar as it refers successfully, it can do so with respect to either the real or the actual though it is contingent (neither necessary nor impossible) whether we know the real or the actual" (Sayer, 2000, p. 12).

The congruence of CR with the framework of this study lies in the fact that CR provides a vocabulary for defining relationships between emergent educational themes as well as the systems and sub-systems of cognition. CR offers a framework for accommodating the complex learning landscape, consisting of multiple levels of meaning, and raising the underpinning mechanisms of learning to the status of equal recognition with pedagogical strategies by acknowledging their interdependent relationships. The application of this multi-levelled and multi-mechanistic model has the potential to empower educators by providing a more defined explanation of the surface level attributes of learning environments, thereby providing the knowledge for informing more finely-tuned learning interventions that meet the needs of individual learners. This model serves as a catalyst for generating questions pertinent to the personalisation of learning, including:

- "How are different levels of expertise defined?"

- "How are different levels of learner prior knowledge defined?"
- "What underlying cognitive mechanisms impact learning?"

CR therefore provides a broadened, amplified ontological view of reality compared with pragmatism, by accommodating realities (the real) that have been validated through RCTs, such as the effects arising from CLT and learning interventions outlined by Bloom (1984). In addition, CR accommodates realities that are sociological constructs, theoretical notions or abstract concepts (Bhaskar, 2008; Fleetwood, 2013, 2014). By acknowledging both the independent knowledge entities as well as constructed knowledge, CR provides a unified notion of the "middle ground" between positivism and interpretivism.

In the context of this study, adopting a CR framework enables the possibility of a research direction that serves as a catalyst for innovation, specifically, one that seeks to account for the multi-levelled reality that has been identified though the literature review; moreover, CR provides the link between the real underpinning cognitive mechanisms of learning and the surface features of learning environments.

In terms of the use of DTELEs in this study as espoused in the information-age model, CR accommodates the multi-stratified layers inherent in the hierarchical structures of information systems, further strengthening the rationale for using a technological architecture for addressing the problem of the study (Carlsson, 2006; Markus & Silver, 2008). The multi-stratified reality of Information Systems (IS) in learning environments was predicted by Jantsch (1972, p. 7), who foresaw a trend towards a multi-layered, transdisciplinary view in higher education that would be facilitated through Information Systems (Adams Becker et al., 2018; Boell & Cecez-Kecmanovic, 2015; Indulska & Recker, 2010). According to Jantsch:

> Ultimately, the entire education/innovation system may become coordinated as a multilevel multigoal hierarchical system through a transdisciplinary approach, implying generalized axiomatics and mutual

enhancement of disciplinary epistemology.

In summary, CR presents an ontological framework that accommodates the complexities of learning and teaching due to its provision of a framework of sufficient breadth to accommodate both intransitive (positivistic) and transitive (interpretivist) domains, as illustrated in Figure 6.2 (below). This framework defines reality as laminated (consisting of the real, the actual and the empirical), as well as multimechanismatic (or multimechanistic)(cf. Mislevy & Ricoscente, 2006a).

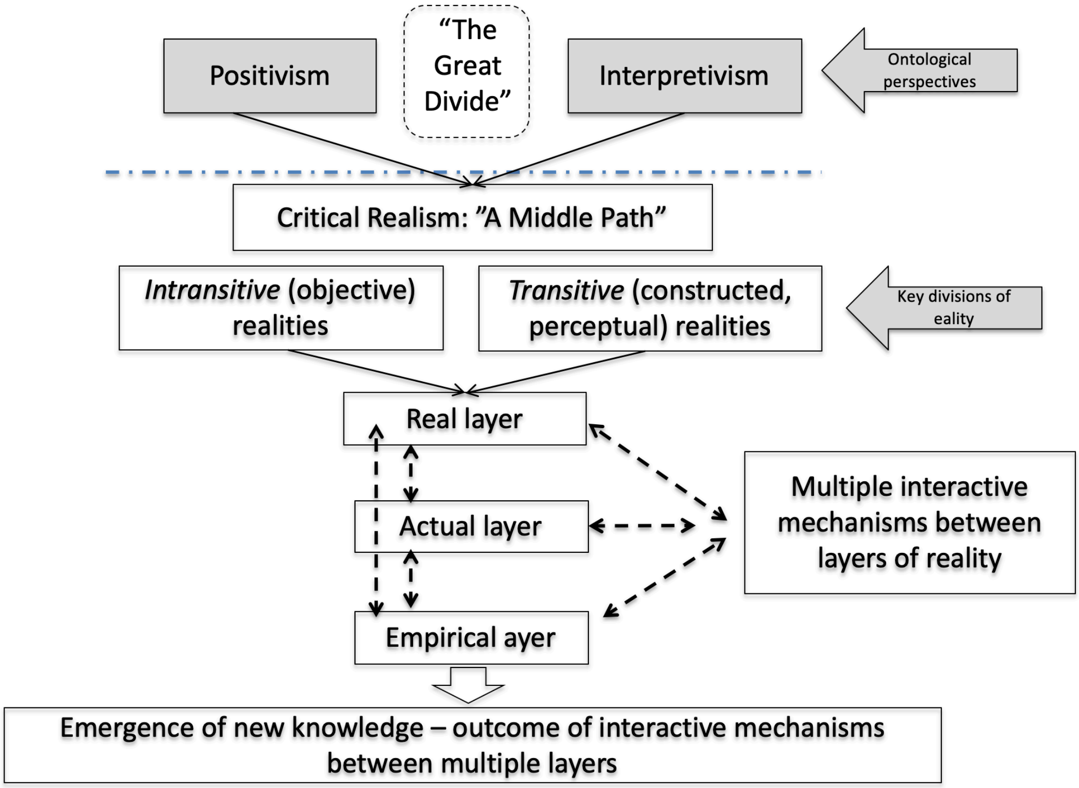


Figure 6.2 An outline of the ontological model of Critical Realism

Notes: This diagram depicts the CR middle path between realism and critical naturalism (adapted from Clark, 2010). CR is defined as a layered or laminated and multimechanismatic (or multimechanistic) view of reality (Bhaskar, 2008; Sayer, 2000). Underpinning or governing mechanisms of reality may be in various states of activation or inactivation and operate independently of their perceived reality.

6.6 Epistemology of the study

Epistemology deals with “the nature of knowledge, its … scope and general basis” (Hamlyn, 1990, p. 242). While ontology describes and explains the generative or underpinning mechanisms, epistemology describes and explains the knowledge generated from the interactions between these mechanisms. In this model, ontology and epistemology are discrete but interdependent constructs. However, alternative views of the interrelationships between ontology and epistemology are also evident in the literature. For example. Crotty (1998, p. 5) states that:

> Were we to introduce it into our framework, it would sit alongside epistemology informing the theoretical perspective, for each theoretical perspective embodies a certain way of understanding what is (ontology) as well as a certain way of understanding what it means to know (epistemology).

Other researchers concur with Crotty’s view. For example, Maynard (1994, p. 18) suggests that the epistemological framework of a study provides a philosophical basis for different categories of knowledge and the criteria for defining their legitimacy and adequacy. The inclusion of a philosophical basis for a study implies that the ontology and epistemology are inextricably bound together.

In contrast to Crotty and Maynard’s position, Bhaskar (2008, 2011) presents a separately defined ontology, adding a deeper foundational layer to their model, as follows:

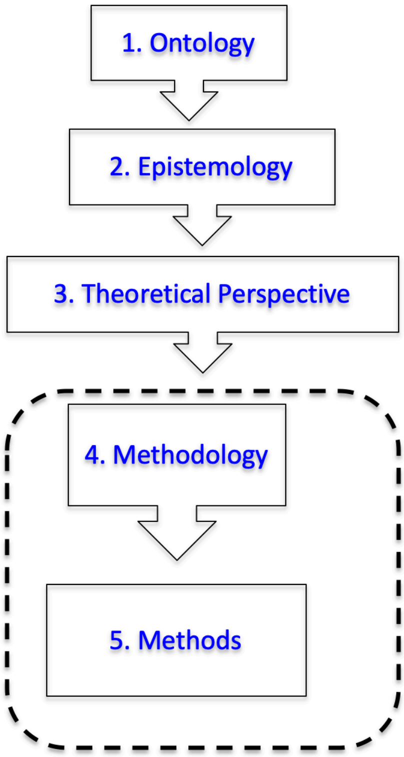


Figure 6.3 Methodology with ontological stratum derived from Critical Realism

Bhaskar's model provides a more congruent framework for the current study.

The key reason for this is that CLT is based on a multi-layered and multi-mechanistic model of cognition that requires a separate ontology to accommodate its complexity and explain its functions. CR provides a framework for understanding the structures and mechanisms of human cognition that give rise to knowledge. With regard to CLT, learning is viewed at two levels, as follows:

1. underpinning mechanisms based on a model of human cognitive architecture

2. effects and strategies arising from RCTs that investigate the particular levels of interaction between these mechanisms.

Figure. 6.3 expands the overall perspective of the study to include both ontological and epistemological frameworks. In this study, CR fulfils the ontological role as it defines learning in terms of a multi-levelled, multi-mechanistic "engine" that underpins the epistemological framework of the study. Elaborating on this concept, Fleetwood (2014, p. 208) refers to a "multiplicity of mechanisms" and Bhaskar (1998, p. 600) refers to a multiplicity of "changing mechanisms, agencies and circumstances" to explain the complex underpinning levels that give rise to the stratified nature of reality.

The well-known heuristic, "consider the prior knowledge of the learner when teaching new knowledge" (Masters, 2018; Merrill, 2002; Reigeluth & Carr-Chelman, 2009), is used to illustrate the principle of a layered reality. The notion of prior knowledge may provide a generalised approach to pedagogy, but it lacks the level of detail to accommodate personalised or individualised teaching i.e. the specific strategies required to teach learners with diverse needs (cf. Sweller, 2006a, p. 325). In contrast, the CR model assumes a more stratified view by setting up conditions for interrogating the meaning of prior knowledge at a more nuanced level. As a result, interpreting the notion of prior knowledge through the lens of CR may result in the following representation, where the known (current state of learner's knowledge) and unknown (desired new learning) each have different levels of stratification in ascending order from low to high.

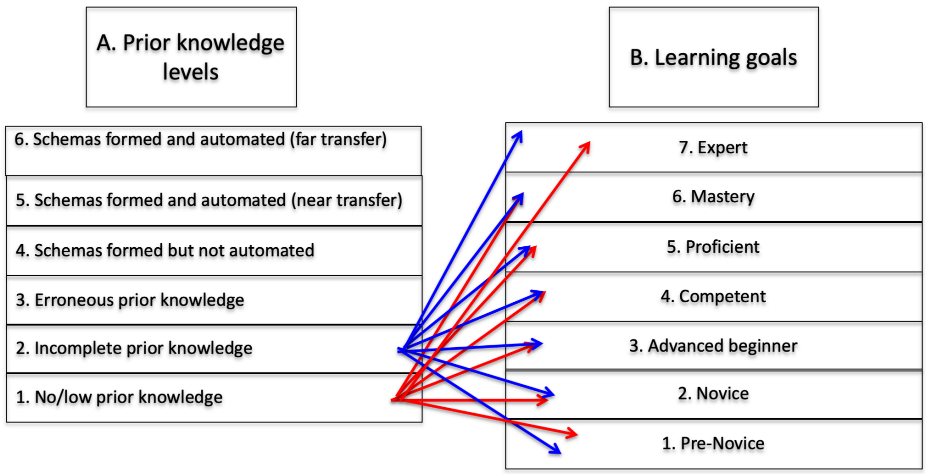


Figure 6.4 A representation of prior knowledge and new knowledge levels

Notes: This figure represents a multi-layered view of going from the known (A) to the unknown (B) through the lens of CR, where both the known and the unknown are viewed in terms of multiple defined levels.

Figure 6.4 (above) illustrates two factors (A, the known and B, the unknown) in the learning environment as interpreted within a CR framework. Mechanisms are activated at different levels from each factor and may interact with each other to produce new emergent knowledge. A scenario illustrates this point: a learner with level 1. prior knowledge who needs to acquire level 5. new information, will require a different set of learning interventions compared with a learner with level 5. prior knowledge requiring the acquisition of expertise (level 7.). This figure illustrates how CR supports a personalised learning pedagogy that requires a detailed analysis of the learner's prior knowledge in order to assign targeted interventions that support learning goals.

Figure 6.4 illustrates the complexity associated with considering levels of learner prior knowledge and curriculum goals, both of which occur at multiple levels. Finally, Figure 6.4 also demonstrates how dealing with multiple capability and curriculum levels aligns with the underpinning ontological paradigm of CR, which has a framework that accommodates the multiple levels of reality that require consideration in personalising learning pathways – the real, the actual and the empirical.

The assumed ontological and epistemological frameworks therefore have implications for the personalisation of learning, including the allocation of time for learners to master new information. The layers and mechanisms comprising factors A and B of learning demonstrate how CR is suited as an ontological framework for the study through its stratified view of reality. In summary, Figure 6.4 presents the multimechanistic (Bhaskar & Danemark, 2006) and emergent (Sayer, 2000) themes espoused within CR.

6.7 Towards the translation of theory to practice in developing CLEMS

Previous chapters have identified the effects and strategies arising from CLT as a suitable knowledge base for evaluating the quality of evidence-based learning design. To advance this knowledge base towards a useable software instrument, it is expedient to start with the end-user in mind – typically, an educator in in situ learning environments. This process requires a series of relational diagrams and flow-charts to illustrate functions and their interrelationships. To initiate the theory-to-practice process (Gredler, 2005), the following questions are relevant to designing then realising the theoretical functions of CLEMS as a useable prototype within a CLT framework:

1. How will CLEMS support educators in identifying deficiencies in evidence-based course content ?
2. How will CLEMS support educators in diagnosing deficiencies in evidence-based course content for individual learners?
3. How will CLEMS support educators to implement and validate the impact of evidence-based strategies in courses?

These questions summarise the two core scenarios supported by CLEMs. First, the evaluation of courses, units or other instructional interventions in which educators identify areas where scope exists to implement strategies arising from CLT. Secondly, when educators diagnose specific barriers, bottlenecks, or troublesome knowledge using the set of diagnostic tools developed for this purpose (Figure 10.16, 10.17 and Appendix F), develop NOE to target and address these issues, then evaluate the impact of NOE interventions.

In both scenarios, the educator's goal is to conduct a detailed analysis of the quality of learning design and devise targeted interventions for advancing learners to the next level of expertise. Figure 6.5 illustrates this process.

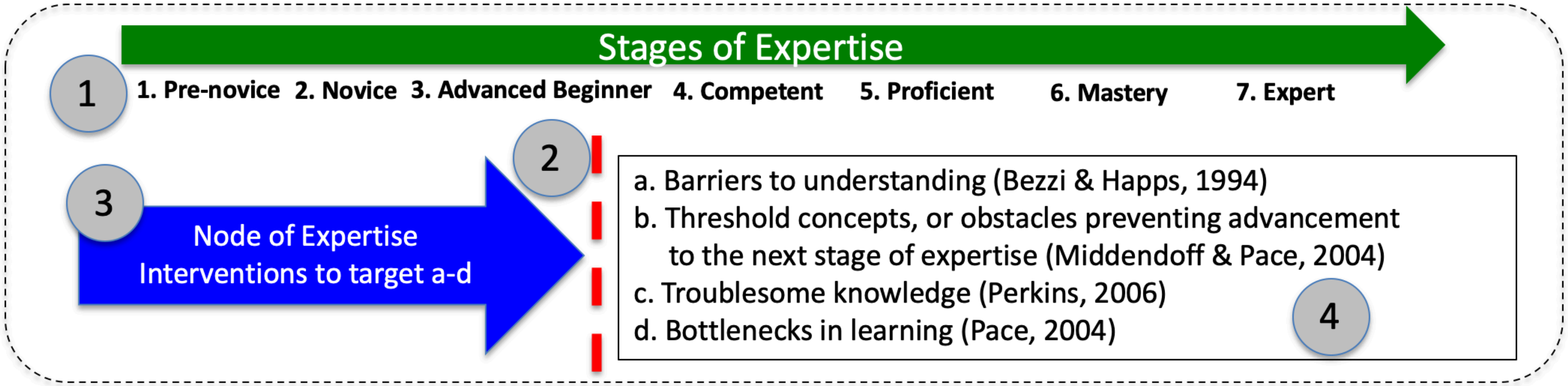


Figure 6.5 Expanded conceptual model (1) of the Dreyfus and Dreyfus (1980) expertise model

Notes: This expanded model has been adopted in this study (steps 1–7) to define a more nuanced view of stages in the development of expertise than the model proposed by Dreyfus and Dreyfus (1980) which has only 5 steps: novice, advanced beginner, competent, proficient and expert.

This model supports the identification of barriers (2, red dotted line) encountered by learners at each level in order to serve the goal of overcoming these barriers through the design and implementation of targeted NOE interventions (3). Barriers (4) are variously expressed in the literature as: a. barriers to understanding b. threshold concepts, or obstacles preventing the learner's advancement to the next stage of expertise c. troublesome knowledge; and d. bottlenecks in learning.

This model represents stages and is intended to be applied flexibly in learning environments due to the overlap of stages which is likely to occur with learners. For example, a novice (Stage 2) may require clarification of concepts in order to advance rapidly to competent (Stage 4) or Proficient (Stage 5) in a particular area of knowledge. This model may also be useful for designing the scope and sequence of curriculum materials in knowledge domains e.g. teachers and learning designers may refer to it while engaging with subject matter experts to develop course materials at appropriate stages for particular learners.

In summary, Figure 6.5 supports the conceptual framework of this study by articulating a high-level pedagogical model for educators to improve the quality of learning design in courses as well as for individual learners. The theoretical model of CLEMS, as represented in Figure 6.6, represents the processes that the educator will engage to diagnose, design, implement and automate NOE, as follows:

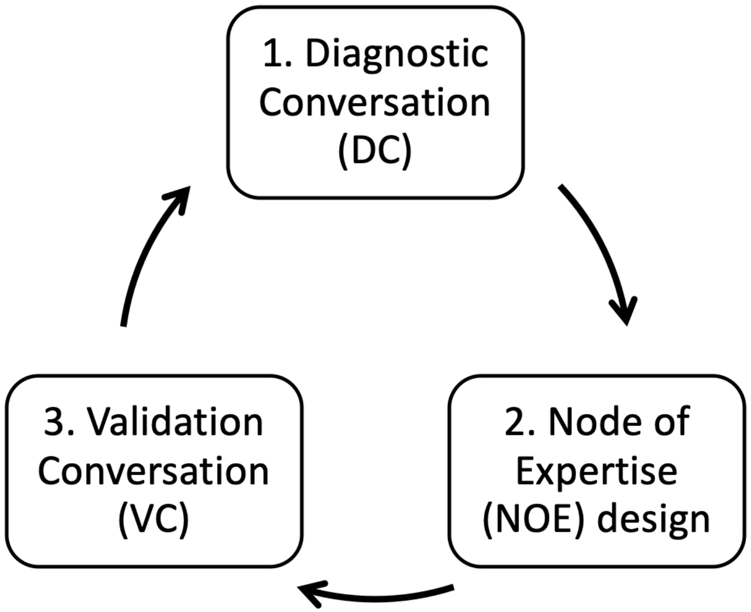


Figure 6.6 The DC–NOE–VC model for supporting schema formation and automation

Notes: This proposed model underpins the pedagogical process on which CLEMS has been designed and supports a personalised, mediative–adaptive paradigm of schema formation and automation for novice learners. The teacher takes a key role in curating the 3-stage process using CLEMS as a learning management tool (see Figure 10.16, 10.17).

Stage 1: Conducting Diagnostic Conversations (DC)

A DC is situated in a specific knowledge domain and includes diagnostic questions by the teacher about the learner's understanding of domain-specific knowledge as well as the learner's heutagogical capability (see Chapter 10, Figure 10.15).
For example, the learner may be asked the key questions by the teacher to ascertain their mental representation of learning concepts, such as:

- "How are you thinking about this?"
- "What approach are you using for solving this problem?"
- "What picture do you have in mind for this concept?"
- "What do you know about the way experts solve this type of problem?"
- "How confident do you feel about solving this type of problem?"

Based on answers to such questions, the teacher defines barriers or troublesome knowledge encountered by learners in order to identify and repair erroneous or incomplete mental representations. In addition, the teacher may use the proposed diagnostic tools (see Figure 10.16, 10.17, Appendix E) to support the DC. These include:

a. Expertise Pathway diagram (see Chapter 10, Figure 10.17)
b. Fluency +- 1 diagram (see Appendix E)
c. Prior Knowledge/Heutagogy Quadrants (see Chapter 10, Fig, 10.16)

Stage 2: Designing Nodes of Expertise (NOE)

A NOE is a learning intervention that has the goal of a skilled performance outcome in a chunk of domain-specific content, where skilled performance is an indicator of automated schemas (Sweller, 1999, p. 44). A NOE therefore represents a synthesis of parameters that contribute to forming accurate automated schemas and is similar to a threshold concept (Land, 2014; Land, Meyer & Flanagan, 2016; Meyer & Land, 2003, 2006).

Based on the DC, the teacher provides a description statement of the NOE i.e. the NOE encapsulates a key idea, concept, process, procedure or principle for the learner to master and may include the presentation of abstract ideas in concrete ways such as analogies, metaphors, object lessons, or models (theoretical or practical).

High quality NOE will be more closely related to authentic contexts of application of content and will also be informed by experts through the CTA process (Chi, de Leeuw, Chiu & LaVancher 1994; Clark, Feldon, van Merriënboer, Yates & Early, 2008). Part of the NOE is defining an expected time–to–mastery that is developed in discussion with the learner, taking the learner's prior knowledge and heutagogical capability into account (Bloom, 1968, 1984) so that the learning process can occur without being truncated prior to automation being attained and providing sufficient time to activate the LTWM mechanism (Ericsson and Kintsch, 1995).

The learner may be removed from the usual time flow of the class and allowed sufficient time to engage in deliberate practice (Ericsson, Krampe & Tesch-Romer, 1993) until schemas have been automated. The NOE may include:

a. expert support for the learner during the implementation of the NOE, with a cautious approach taken to the learner's re-engagement in the usual work of the class until the schema encapsulated in the NOE has been formed, automated and demonstrated as skilled performance of problem solving tasks or other tasks underpinned by the NOE

b. varied environment such as "sprints" (intensive, supported learning environments) and "jogs" (self-managed learning environments) i.e. the adjustment of time and intensity of learning and practice with the singular goal of schema automation

c. CLT effects and strategies, for example:

- sequences of varied worked examples, completion problems and traditional problem tasks
- the learner is taught to use high quality self-explanations that form deep conceptual connections through to complement worked examples
- goal-free practice problems may be used i.e. replacing convergent goals with open-ended or indeterminate goals such as instructions in a geometry problem where "find the angle" is replaced with "find as many angles as you can" (Sweller, 1999, p. 38)
- formatting that induces split-attention for the learner is removed from materials
- the modality effect is used to engage dual channels of working memory
- redundancy is removed from learning materials i.e. content is not repeated in different processing channels (audio and visual) in order to reduce cognitive overload
- use of the imagination effect for review of work after a base of prior domain knowledge has been learned
- use of other CLT effects and strategies as applicable, e.g. teaching learners the self-management skills of how to reformat materials that are not compliant with the CLT strategies in order to reduce cognitive loads (Mirza et al., 2020, p. 157).

In addition, NOE include identified heutagogical issues, barriers or blockages that the learner is encountering. These may include issues in the following areas:

- learners have engaged in rote learning of content knowledge without attaining a deep inferential understanding of the meaning and relevance of it i.e. the learner may have overloaded working memory without engaging in schema formation and automation
- learners do not understand the context and purpose of the domain knowledge
- learners have internal or external motivational issues
- learners do not understand how the domain knowledge connects to their aspirations and interests
- learners do not understand how experts apply the domain knowledge in authentic contexts
- learners have poor understanding of how working memory and long-term memory operate together and therefore have less than optimal outcomes for the effort they are applying
- learners do not manage their study time and study environment to the best effect to form and automate schemas.

Stage 3: Conducting Validation Conversations (VCs)

A VC consists of the teacher reviewing learner's performance after a completed NOE intervention. The teacher prepares for the VC by reviewing the NOE and the results of a post-test that has been set to ascertain the impact of the NOE intervention. The following steps are suggested for conducting a VC:

- the teacher interprets the outcomes of the NOE for the learner
- the learner is given the opportunity to reflect on the results of the NOE intervention related to understanding the domain knowledge as well as any heutagogical impact of the intervention

- the comments of the teacher and learner are recorded in CLEMS
- after the DC, the teacher can set another NOE or the learner can return to the regular work assigned to the class or group.

The DC–NOE–VC represents a personalised pedagogy that includes heutagogical factors that impact learning; it may also include the explicit teaching of how cognitive mechanisms and effects operate so learners gain insight into their own cognitive processes and mechanisms (see Appendix F, Figure F1). For example, while teachers may format instructional interventions to reduce or eliminate the split-attention effect, learners may also benefit from knowing how to identify the split-attention effect in learning materials they encounter. Having knowledge of this effect and its negative impact on learning may empower learners to re-format materials to reduce or eliminate split-attention or to seek help in doing so (Mirza et al., 2020, p. 158).

This heutagogical process may be aligned with the self-explanation effect (where a learner's self-explanation might be: I see that these materials are not integrated, which will create a barrier to my learning through increasing cognitive load. I will reformat this material to reduce or eliminate split-attention).

In summary, the relationship between the learner's prior domain knowledge and heutagogical capability has implications for:

a. learning design e.g. which evidence-based effects to include in the design of the learning intervention
b. the level of teacher mediation required for various learner profiles
c. the structure of the curriculum for various levels of prior knowledge.

Acknowledging the above three factors in learning design strengthens the argument for a curriculum that is seamlessly integrated through incremental knowledge steps and concepts that range from very low to very high levels of expertise (see Figure 6.5). A curriculum designed in this way increases transparency of the learner's progress along the learning continuum from pre-novice to expert, since learners can engage with it at levels that are adapted to their current knowledge and capability.

6.8 Chapter summary

This chapter focused on defining the conceptual framework of the study, which served the purpose of "linking all of the elements of the research process" including the researcher's approach to, and interest in, the problem being addressed, the themes arising from the literature, and the interconnected theoretical frameworks and methods of which the study is comprised (Ravitch & Riggan, 2017, p. 6). This chapter outlined the key factors, variables and constructs of the study, in addition to the presumed relationships among them by providing the following:

1. A discussion of different definitions of conceptual frameworks to clarify the purpose of the conceptual framework for this study as a blueprint for synthesising disparate theoretical models into the technical specifications for CLEMS (Appendix Q)
2. The confirmation of two key parameters for filtering the appropriate research for informing the design of CLEMS
3. The rationale for engaging CR as the underpinning ontological and epistemological framework of this study due to its alignment with CLT the model of human cognitive architecture and learning processes
4. New vocabulary to define key processes associated with the pedagogical application of CLEMS, including diagnostic conversation (DC), NOE and validation conversation (VC);

in addition, the adoption of the term heutagogy as an umbrella term for defining the parameters that constitute self-determined learning capability (Hase & Kenyon, 2001). These parameters include affective factors such as self-motivation (Kalyuga, 2011b; Martin, 2016), self-efficacy (Vasile, Marham, Singer & Stoicescu, 2011), learner agency (Kahn, Qualter & Young, 2012), mindset (Heckhausen & Dweck, 1998), self-regulation (Blaschke, 2019; Eitel, Bender & Renkl, 2020; Hase & Kenyon, 2001) and may be extended to the metacognitive skill of how to apply cognitive load theory strategies to learning materials that are not compliant with CLT (Mirza et al., 2020, p. 157).

5. The DC–NOE–VC pedagogical model represents the synthesis of parameters that contribute to the formation and automation of schemas. This model represents how CLT informs the design of CLEMS.

The next chapter articulates the methodology and methods engaged to conduct the study.

Chapter 7 – Methodology and Methods

7.1 Introduction

This chapter consists of two key sections. First, the rationale for the choice of research methodology and methods for this study; secondly, how the methodology and methods were applied as the study was conducted.

The study follows a structured approach which is directed towards the addressing the research question through the design and development of CLEMS.

The methodological approach that was selected due to its support for the nature of this enquiry was design-based research (DBR) which is also called design science (Carlsson, 2010; Collins, 1991; Collins, Joseph & Bielaczyc, 2004; di Sessa & Cobb, 2004; Hevner, 2007; Niehaves, 2007), design experiments (Cobb, Confrey, diSessa, Lehere & Schauble, 2003) and educational design research (McKenney & Reeves, 2013; Plomp, 2013; Reeves, 2011, 2015; Reeves & Oh, 2017; van den Akker, Gravemeijer, McKenney & Nieveen, 2006). DBR has its foundations in the cyclical, iterative research process espoused within action research (Bradbury, 2015; Carr & Kemmis, 1986; Cole, Rossi, Purao & Sein, 2005; Cronbach, 1982; de Villiers, 2005; Dick, 1997, 2000a, 2000b; Herr & Anderson, 2005; Kemmis & McTaggart, 1988; Lewin, 1946; Livari, 2007; Wepson, 1995), but extends this paradigm by using technological frameworks to address research problems, therefore positioning it within an information systems (IS) framework (Carlsson, 2012; Carlsson, Henningsson, Hrastinski & Keller, 2011; Conboy, Fitzgerald & Mathiassen, 2012).

DBR has gained considerable momentum with IS research (Carlsson, 2011; Gerber, Kotze & van der Merwe, 2015) and its congruence with IS research has been noted (Indulska & Recker, 2010). DBR provides a framework for this study within a technological or IS domain. By embracing the potential of technological systems for improving learning (Sandoval, 2004), DBR therefore offers a theoretical basis for expanding the study into an interdisciplinary framework that embraces technology as part of the solution to an identified problem (Schoenfeld, 2009). The adoption of an IS framework provides insight into the "how?" aspect of the research question by providing a unifying, technological vehicle for realising the goal of the study.

7.2 The influence of action research on design-based research

Due to the developmental nature of the study, the qualitative, cyclical process of research as exposited by Lewin (1946) in action research was initially considered a suitable methodology for addressing the key question of the study. Action research was designed as a qualitative methodology for addressing ill-defined incomplete or "fuzzy" problems (Carr & Kemmis, 1986; Dick, 2000; Kemmis & McTaggart, 1988) within communities of practice using cyclical research iterations that bring increasing clarity to the problems.

Action research supports the perspective of the researcher as an insider who conducts investigations to understand the nuances of problems being experienced by groups of people (Lewin, 1946, pp. 40–44). This approach aligned with the current study, which aimed to address and contribute understanding to an issue in the educational community with regard to the evaluation of the quality of learning design (Ariff, Sulong, Khalifah & Omar, 2008.; Donald et al., 2009; Phillips, McNaught & Kennedy, 2012).

Action research (Carr & Kemmis, 1986; Dick, 2000a, 2000b; Kemmis & McTaggart, 1988; Lewin, 1946) supports research paradigms consisting of repeated research iterations following a plan–act–observe–reflect cycle. By engaging with an initial, possibly ill-defined problem, action research provides a model for deriving solutions over a set number of iterations to bring issues into clearer focus, as illustrated in Figure 7.1 below:

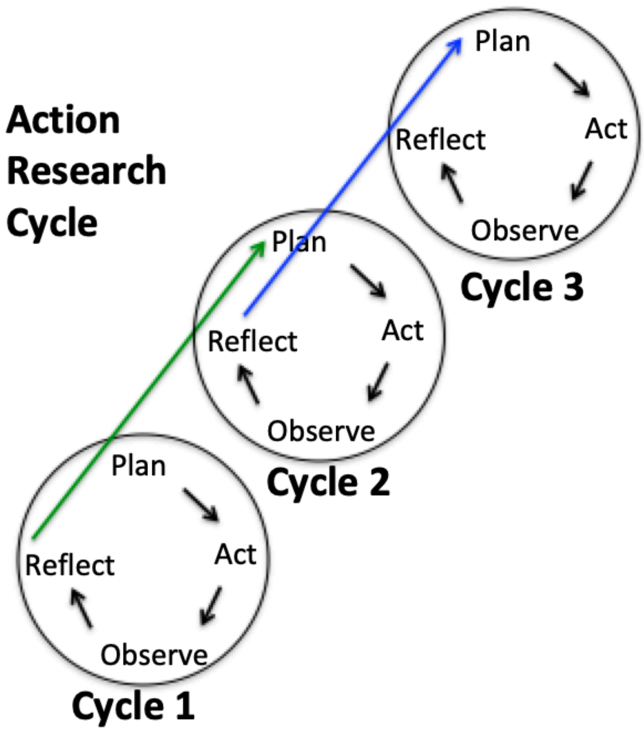


Figure 7.1 Adapted model of the action research cycle of Plan–Act–Observe–Reflect (Kemmis & McTaggart 1988)

Notes: This figure llustrates three research iterations for the progressive refinement of solutions to problems. Diagram by D. Isaacson, adapted from Kemmis & McTaggart (1988) and Lewin (1946).

Action research represented a research methodology with potential for addressing the research question but its derivative methodology of DBR demonstrated greater congruence with the specific goal of the study to produce a new evaluation artefact: CLEMS.

In addition, action research does not necessarily specify an outcome such a practical solution to a problem (Bradbury, 2015; Carr & Kemmis, 1986; Dick, 2000a, 2000b; Kemmis &

McTaggart, 1988; Lewin, 1946), whereas DBR is goal-driven towards the production of a practical intervention which has the goal of improving learning environments and outcomes (Brown, 1992).

7.3 Design-based Research

The DBR approach has been defined as having five characteristics, as described by The Design Based Research Collective (2003, p. 5):

1. the central goals of designing learning environments and developing theories or "prototheories" of learning are intertwined
2. development and research take place through continuous cycles of design, enactment, analysis and redesign (Cobb et.al., 2003; Collins, 1992; Design Based Research Collective, 2003)
3. research on designs must lead to shareable theories that help communicate relevant implications to practitioners and other educational designers (Anderson & Shattuck, 2012)
4. research must account for how designs function in authentic settings (Brown, 1992). It must not only document success or failure but also focus on interactions that refine our understanding of the learning issues involved (Design Based Research Collective, 2003)
5. the development of such accounts relies on methods that can document and connect processes of enactment to outcomes of interest.

The purpose of DBR may be summarised as "a practical research methodology that could effectively bridge the chasm between research and practice in formal education" (Wang & Hannafin, 2005) and a methodology through which "Design-based researchers' innovations embody specific theoretical claims about teaching and learning, and help us understand the relationships among educational theory, designed artifact, and practice" (Design Based Research Collective, 2003, p. 5; Livari, 2007).

These definitions are congruent with the purpose of the study in two areas: develop a new evaluation instrument for improving the quality of learning design; and base this design on a cohesive theoretical framework. The theoretical aspect of CLEMS plays a key role in DBR, since the aim is not to simply produce "what works" in a pragmatic sense. DBR also has the goal of contributing to the understanding of theoretical principles related to developing artefacts for improving learning environments (Design Based Research Collective, 2003) These goals align with the qualitative and interpretivist paradigm of the study (Crotty, 1998) to stimulate the emergence of CLEMS with specific characteristics and functions that support improved learning. In further support of using a DBR methodology to conduct this study, Cotton, Lockyer and Brickell (2009) have set a precedent by using the Reeves (2006) model of DBR implementation to develop an electronic performance support system (EPSS) for informing pedagogically effective learning design.

The adoption of DBR as a methodology implies the rejection of alternative research methodologies. While each methodology that was considered contained components that were relevant to the current study, the overall goal of the study was satisfied within the DBR paradigm.

Rejected methodologies, as well as the reasons for their rejection, included the following (Sauro, 2015):

1. ethnography, since the study was not primarily derived from an anthropological context that was concerned with customs and social habits of people or population groups and their meanings (Naidoo, 2012);

2. phenomenology, since the study is not primarily concerned with the consciousness and objects of direct experience and this paradigm, or as Gallagher (2012), expressed it: “the phenomenologist, the investigator of consciousness, studies his or her own experience from the point of view of living through that experience”. This approach was therefore not aligned with the research question of the study.

3. case studies, since the current research does not use case studies for theory building or theory testing (Bhattacherjee, 2012);

4. survey research, since the study did not have the goal of using standardised tests to gather data, including people’s preferences, traits, attitudes, beliefs or behaviours, nor factual information about them (Ponto, 2015; Ulin, Robinson & Tolley, 2005). The purpose of the study was a particular technological outcome for specific application in educational environments which is not generally a goal of survey research.

5. critical theory, since the study is not focused on philosophical approaches to ideological aspects of culture and literature, nor the historical, social and ideological forces and structures which produce and constrain it (Thompson, 2017).

The conceptual framework (Chapter 6) articulated an integrated theoretical model of CLEMS including an evaluation standard derived from CLT and a technological architecture to support the implementation of this standard within teaching environments. The in situ aspect of the study arises from DBR which seeks to implement learning designs in authentic or “messy” (Brown, 1992) learning environments as opposed to laboratory experiments (Design Based Research Collective, 2003). A recent research direction in CLT has been expressed as needing to validate CLT effects in authentic learning environments (Sweller, Ayres & Kalyuga, 2011, p. 134). The design of CLEMS suggests an approach that will contribute to understanding the conditions and boundaries of CLT effects in actual learning environments. The use of a technological architecture has been identified as a unifying framework for integrating a broad range of functional specifications of CLEMS. These include:

i. the facilitation of an in situ evaluation process to support teachers in improving learning design
ii. the synthesis of additional factors identified in the literature to support the strengthening of learning design, including factors for personalising learning such as social, affective and heutagogical themes
iii. the inclusion of key principles impacting the continuous improvement of learning design and knowledge management such as "double-loop learning" and data analytics (Corrin et al., 2016).

The design of CLEMS, which is therefore represented as a unified system of CLT strategies, heutagogical factors and technology, therefore situates the study within a sociotechnological framework, defined as the detailed study of underpinning mechanisms and processes where social and technical factors are indivisibly integrated (Vojinovic & Abbott, 2012). Moreover, the second part of the research question which focuses on the usefulness of CLEMS to teachers, implies an iterative, design-based development process, again affirming the suitability of DBR as the appropriate research methodology for this study (cf. Cotton, Lockyer & Brickell, 2009).

Having derived a feasible theoretical model for CLEMS in the conceptual framework, the second part of the research question required the theoretical model of CLEMS to be advanced into a working prototype in order for its potential usefulness to educational practitioners to be evaluated and critiqued. In alignment with DBR, the specific methods supporting the research goal included ongoing literature reviews, focus groups, and triangulation of emergent knowledge (Bakker & Van Eerde, n.d; Design-Based Research Collective, 2003; Herrington, McKenney, Reeves & Oliver, 2007; Hevner, 2007; Reeves, 2006).

Boell and Cecez-Kecmanovic (2015, pp. 2, 15; 17, 28, 70) provide a succinct description of the purpose of IS that positions it to serve educational goals in alignment with DBR:

> The Information Systems field is not primarily concerned with the technical and computational aspects of Information Technology. What matters to Information Systems instead is how technology is appropriated and instantiated in order to enable the realization of IS that fulfill various actors' – such as individuals, groups or organizations – information needs and requirements in regards to specific goals and practices.

DBR provides a framework that can be used to evaluate designed artefacts for improving learning environments. DBR enables this process by positioning such artefacts within an IS paradigm that takes account not only of technological factors, but of social factors and needs within social contexts. This point is critical to the study; technology within the IS definition is positioned to serve the needs of the various actors within social contexts by amplifying their capabilities, not dominating, controlling, disempowering or disenfranchising them

7.3.1 Design-based research: The Reeves model

Over the past two and a half decades, DBR has emerged as a methodological approach with increasing potential for conducting research and for the design of technology enhanced learning environments (Brown, 1992; Design-Based Research Collective, 2003; Marshall & Sankey, 2014; Wang & Hannafin, 2005). It has gained increasing recognition for the value it has added to educational research (Barab & Squire, 2004; Herrington, McKenney, Reeves &

Oliver, 2007).

As DBR represents a “family” of approaches (Design Based Research Collective, 2003), it provides flexibility in terms of application within the complex and variable learning environments that constitute technologically-driven, contemporary higher education (Reeves, 2006). The notion of “naturalistic settings” is a feature of DBR (Brown, 1992), which contrasts with laboratory-conducted, RCT educational experiments that may not take into account the “messiness” (Brown, 1992, pp. 147, 167) or complexity of authentic learning environments.

While initially termed “design experiments” (Brown, 1992; Collins, 1992), DBR has been allocated different designations depending on the contexts in which it has been applied (Brown, 1992; Collins, 1992; Wang & Hannafin, 2005).

More recently, DBR has emerged as a viable methodology for PhD research (Abdallah & Wegerif, 2014; Goff & Getenet, 2017), despite potential limitations such as requiring longer time frames than may be manageable within a PhD study program. Herrington, McKenney, Reeves and Oliver (2007) acknowledge potential time limitations related to the use of DBR in PhD studies but in spite of these limitations, they assert that the benefits outweigh the challenges, arguing that DBR represents a feasible methodology for doctoral research studies and therefore candidates should be encouraged to pursue it as a research paradigm.

Reeves (2006) advanced the understanding of DBR and its application by articulating the DBR process as an improved educational research paradigm over traditional research methodologies. Reeves supports his drive towards a renewed direction in evaluating technological innovations by the lack of specific guidelines arising from predictive design research. Reeves’ conclusion was the result of a five year meta-analysis of research into technological innovations in education (Reeves, 1998), concluding that little of real value was added by this body of research, hence his proposal for an enhanced model of conducting research in digital technologically enabled learning environments (DTELEs) (cf. Brown, 1992; reeves, 2006). Reeves appeals for a greater degree of rigour in determining the factors that improve learning in technologically enabled learning environments in order to provide practitioners with guidelines for improving learning in authentic, contexts that have been defined as “messy” (Brown, 1992; Reeves, 2011) due to large numbers of variables.

Figure 7.2 provides a comparative process chart of traditional, predictive research and DBR. Each design research cycle may be compared with the action research cycle stages of: analyse (plan) –develop (act) –(test and refine) observe–(reflect) reflect (Carr & Kemmis, 1986; Kemmis & McTaggart, 1988).

This demonstrates the parent–child relationship between action research and DBR, with DBR being situated in a technologically enabled learning environment.

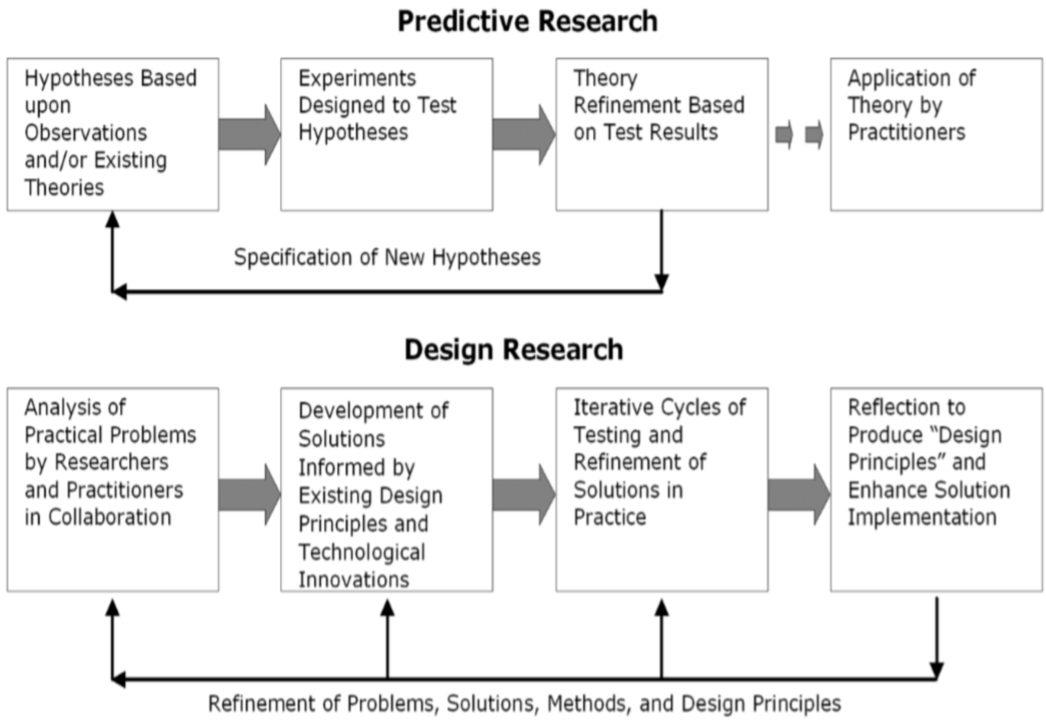


Figure 7.2 The Reeves (2006) model of design-based research (used by permission).

Notes: The Reeves model of DBR (Reeves, 2006) specifies the processes that may be engaged for achieving the development of software artefacts (Herrington, McKenny, Reeves & Oliver, 2007) that address identified issues in education. The Reeves model consists of four iterative stages of research: analysis, development, iteration and reflection.

To this point in the study, the problem has been defined and a research question for addressing it has been articulated. Moreover, a theoretical solution has been proposed based on existing design principles and technological innovations. Having laid the foundation through the first stage of the Reeves model, the study could progress towards implementing the development of CLEMS through three research iterations and an integrated, reflective process to produce design principles.

7.3.2 Limiting the study to three research iterations

The limitation of the study to three iterative development cycles was imposed due to time constraints. However, these constraints had the advantage of ensuring the focus of the study remained on its end goal of developing CLEMS through the three iterations. Each iterative stage of research was assigned a goal regarding the development of the new instrument as follows:

a. Iteration 1: Designing CLEMS

b. Iteration 2: Evaluating a proof of concept of CLEMS

c. Iteration 3: Trialling a prototype of CLEMS.

Flexible time frames for each iteration ensured that each goal was satisfactorily achieved

7.4 Study design

Data collection was planned through written instruments and triangulation of data findings between focus groups, as well as a continued literature review to confirm or disconfirm findings. In addition, the emerging findings were compared with the conceptual framework of CLEMS (see Figure 6.6). Appropriate ethics approvals were applied for and issued before carrying out the empirical research, the category of which was classified as low-risk and issued under the University of Adelaide approval codes 2014-081 and 2017-081.

Following each research iteration, the research data was consolidated and preparations were made for engaging in the following iteration (Figure 7.3) as follows:

1. Iteration 1

    Goal: Design CLEMS (specify the features and functions based on the theoretical model arising from the literature review).

Cycle stages: analyse–develop–test–reflect

2. Iteration 2

Goal: Review a proof of concept of CLEMS

Cycle stages: analyse–develop–test–reflect

3. Iteration 3

Goal: Trial the software prototype.

Cycle stages: analyse–develop–test–reflect.

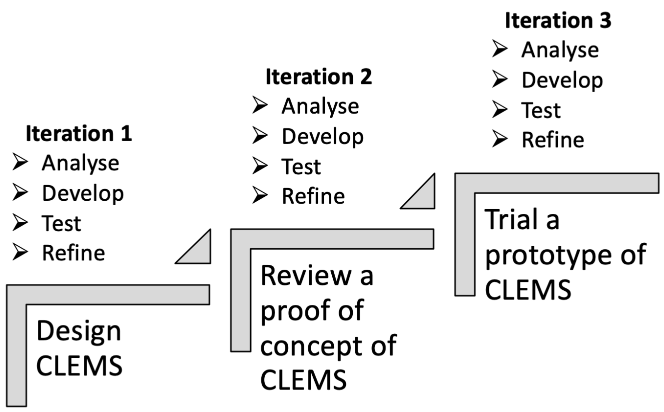


Figure 7.3 Outline of the three research iterations of this study

Notes: This model demonstrates the progressive process of developing CLEMS from theoretical design specification to operational prototype using the Reeves model of DBR (Reeves, 2006).

7.5 Data collection methods

The key methods of collecting data to inform the development of CLEMS were:

a. the chronological process of data gathering over three consecutive research iterations

b. conducting focus group events with participants who were expert informants in education

c. triangulation of emerging data in the discussion of data findings between research iterations and the three focus group findings, with continuous ongoing literature reviews and also with the conceptual framework of CLEMS (see Figure 6.6)

7.6 Implementation process of the study

The process of implementing the study consisted of a number of stages. First, ethics approval was obtained for conducting the research; secondly, the participant recruitment strategy was planned; thirdly, the organisation of focus groups was planned in detail, including time, venue booking, and sequence of events within the focus group, as well as the production of resources to be used in the focus groups for both ethics compliance purposes and participant support; fourthly, methods of eliciting information including questionnaires, participant response sheets and discussions with note taking were devised and designed according to the goals of each focus group.

7.7 Data analysis

7.7.1 Overview of data analysis strategy

The data analysis strategy for the study was derived from the qualitative data analysis models posited by Ulin, Robinson and Tolley (2005) as well as Huberman and Miles (1994). This strategy is depicted in Figure 7.4, which includes phases of field research and desk research that match the research iterations carried out in the study.

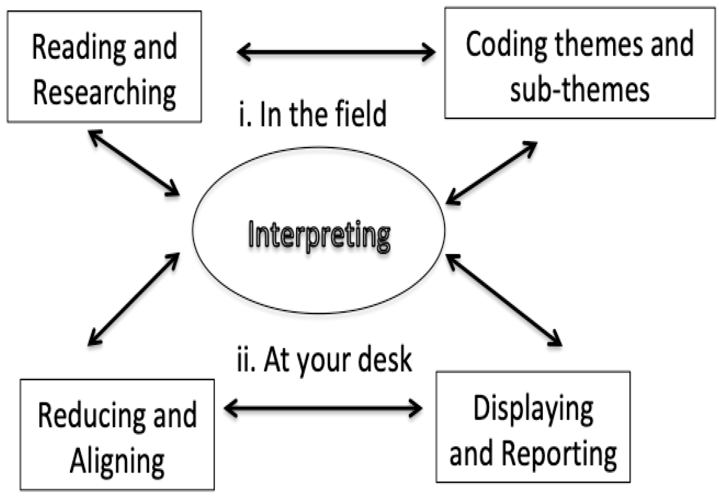


Figure 7.4 The data research analysis strategy used in the study

Notes: This high-level model is based on Huberman & Miles (1994, p. 429). The key guidelines of Ulin, Robinson and Tolley (2005) complement the model in Figure 7.4 by specifying the detailed process of each phase (reading and researching, coding themes and sub-themes, reducing and aligning, and displaying and reporting).

The detailed data analysis process is as follows:

1. obtain thorough familiarisation with data
2. use the research question to guide the organisation of data
3. obtain a holistic view of the collated data
4. search for similarities and differences between data sets
5. search for core meanings that support the holistic view of the data
6. provide an overall interpretation of the findings through: identifying and linking themes, elaboration on the relationship between responses to the research question, and extrapolating the findings beyond the context of the research.

In alignment with the above processes and principles, the overall data analysis strategy was aligned with the goal of each research iteration and focus group Section 7.4

Data was categorised into themes (Appendices 9–11) where:

> A theme captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set. An important question to address in terms of coding is: what counts as a pattern/theme, or what ‘size’ does a theme need to be? This is a question of prevalence, in terms both of space within each data item and of prevalence across the entire data set” (Braun & Clarke, 2006, p. 82).

Patterns, themes and trends were categorised and coded to support the goal of each research iteration. Gibbs (2007) observes that Thematic coding is a type of qualitative data analysis that comprises recording or identifying items that are linked by a common theme or idea which allows an indexing process to occur by placing text into categories and thereby establishing a thematic framework.

In addition to a thematic framework for categorising and classifying data for further analysis, principles were followed for establishing content validity, construct validity, ecological validity, or the generalisability of the data to real-life settings (Andrade, 2018), reliability and data value. These principles were established and applied to identify and mitigate potential biases in the interpretation of data, as follows:

a. Content validity, which seeks to determine the representative nature of the gathered data to the field of endeavour (Salkind, 2010), was established through using the research question to guide the content and goal of the study and establishing the alignment between the stated goals of each research iteration and the data that emerged from each iteration

b. Construct validity (Ginty, 2013; Kelly, 1927; Westen & Rosenthal, 2003), which is the process of validating that the intended instruments gathered what they claimed to gather, was established through discussion and critique within focus groups, triangulation of gathered data between research iterations and alignment with the stated goal of each research iteration;

c. Data value, which is defined as the usefulness or value of the research data in addressing the research question, was established through the explicit alignment of the emerging data with the stated goals of the study in the form of the main research question and the stated goals of each research iteration

d. Reliability of emergent data was established through: appropriate size of focus groups for the needs of study; the qualifications of focus group participants; triangulation of emergent data between groups (internally) and between iterations and emergent data from the literature review (external) (Noble & Smith, 2015; Ulin, Robinson & Tolley, 2005) and between emergent findings and the conceptual framework of CLEMS (see Figure 6.6). As each iteration was intended to provide the groundwork for the next, the overall findings of each iteration were summarised and evaluated for their sufficiency to inform the next iteration. The variations in time between research iterations were necessary to ensure sufficient time to plan the following iteration as thoroughly as possible.

7.7.2 Data organisation and coding

Ulin, Robinson and Tolley (2005, p. 147) present a flexible and emergent approach to coding due to the fact that:

> There are no real guidelines on how finely to code your data. It may depend as much on personal style as on your research aims or professional field. We suggest coding your first several texts using fairly broad tables that correspond to the study's main research questions … However, as you continue to read and code texts, you may find that such broad headings give you little sense of the main ideas emerging from your data. You will need to

develop new codes that divide these themes into smaller components or subthemes.

Data was thematically coded (Chi, 2006; Gibbs, 2010; Ulin Robinson & Tolley, 2005) according to the following five categories using a descriptive coding protocol (Miles & Huberman, 2014

1. Theory (Th)

Responses relating to theoretical aspects of CLEMS

2. Technical and systemic (T&S)

Responses relating to technical functions of CLEMS

3. Content and information (C&I)

Responses relating to content and information within CLEMS

4. Teacher (T)

Responses relating to the role and functions of the teacher

5. Learner (L)

Responses relating to the role and functions of the learner**.**

7.7.3 Resources and tabulated summary of findings from three focus groups

The following appendices contain the preparatory information and resources for each of the three focus groups, as well as the collated, coded and summary of raw data from each focus group.

Appendix H: Focus Group 1 Resources

Appendix I: Hosted MOODLE learning management system instance for provision and storage of participants information

Appendix J: Focus Group 2 Resources

Appendix K: Focus Group 3 Resources

Appendix L: Summary and Coding of Raw Data From Focus Group 1

Appendix M: Focus Groups Procedures

Appendix N: Summary and Coding of Raw Data From Focus Group 2

Appendix O: Summary and Coding of Raw Data From Focus Group 3

7.7.4 Interpretation of findings

Braun and Clarke (2006, p. 13) emphasise the need for depth of analysis of emergent data rather than limiting interpretation to a descriptive level, using the terms semantic and latent to define these differences:

> If we imagine our data three-dimensionally as an uneven blob of jelly, the semantic approach would seek to describe the surface of the jelly, its form and meaning, while the latent approach would seek to identify the features that gave it that particular form and meaning. Thus, for latent thematic analysis, the development of the themes themselves involves interpretative work, and the analysis that is produced is not just description, but is already theorized.

This approach aligns with the conceptual framework of the study to interpret the emerging research findings thematically, holistically and continuously while being guided by the research question.

7.8 Summary

This chapter identified and justified the use of DBR as a suitable methodological paradigm for this study. DBR was aligned with the key goal of developing CLEMS for improving learning environments as well as articulating the principles on which it is based, thereby informing the theoretical underpinning of the artefact. Moreover, DBR, which is grounded within the discipline of IS, supports the use of technological innovation as a problem-solving strategy (Design Based Research Collective, 2003).

Following this, the specific steps followed in conducting the study were stated in terms of three research iterations using the Reeves (2006) DBR model and interpretive guidelines for the data that have been articulated in this chapter.

The next three chapters (Chapters 8–10) focus on the data that emerged from the three research iterations of the study. The raw data is contained in appendices as referenced in these chapters.

Chapter 8: First Data Chapter - Designing CLEMS

Research Iteration 1 and Focus Group 1

8.1 Introduction

The previous chapter provided an outline of the methodological approach and methods used to conduct the empirical components of the study in three research iterations, with a focus group included in each iteration (Figure 8.1).

This chapter outlines the process followed in each iterative cycle. Supporting documents, information-gathering instruments and raw data are included in appendices. Appendix H includes documentation and data from Research Iteration 1 as outlined in Section 8.2 (below). Appendix P provides an outline of the procedures followed in preparing for focus groups, conducting focus group and processing the gathered data.

8.2 Research Iteration 1

This section outlines the data gathering process for Research Iteration 1. Later sections interpret the data, discuss its validity and reliability and delineate all the processes followed to advance the theoretical model of CLEMS into a useable software instrument prototype.

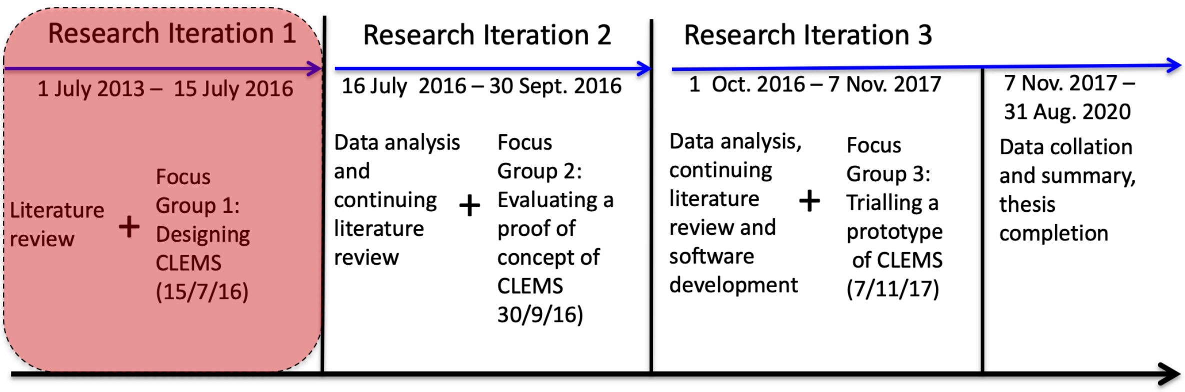


Figure 8.1 Research overview with Research Iteration 1 highlighted

Notes: This iteration is the first of three research iteration consisting of DBR cycles based on the Reeves (2006) model (see Figure 7.2).

The aim of the first iteration was to lay the foundation for the research. It complied with University of Adelaide ethics requirements and protocols. This iteration continued until July 2016, by which time a sufficient volume of the literature review had been conducted to construct the data gathering instruments (Appendix H) in preparation for the first focus group. The first research iteration was the longest one in the study (1 July 2013 – 15 July 2016) as it involved preparing the theoretical framework for the study as well as designing the entire research process.

The first focus group which consisted of 15 participants was run at the University of Adelaide in the School of Education. This focus group titled Designing CLEMS was scheduled from 12.00 pm to 1.30 pm on 15 July 2016.

The roles and numbers of participants in Focus Group 1 were as follows: Instructional Designers (3), Academics (5), Academic researchers (1), Educators (6) (see Appendix L).

Participants in the first focus group were invited to participate via two methods:

1. through a link to a Moodle web portal set up by the researcher at www.elearningdesignphd.com (Appendix I). This website was used to provide general information to participants, and as a repository for the forms required to be completed during focus groups e.g. general background information for participants, participation consent forms, ethics approval references, as well as other required documentation
2. distribution of invitations via email through inter-departmental networking coordinated by the lead study supervisor as well as via the professional networks of the researcher. The range of participants as well as their background and experience, fulfilled the sample size

expectations for this focus group, which was 10–15 respondents. This sample size provided “a small, purposive” sample group (Ulin, Robinson & Tolley, 2005, p. 55) suitable for addressing decisions regarding the content, functions and format of CLEMS. Both the size of the group and the calibre of the participants was deemed sufficient for the purpose of functioning as an expert panel (Ulin, Robertson & Tolley, 2005), consisting of experienced academics, educators, instructional designers and lecturers. The roles and numbers of participants in each focus group are listed in Appendices L, N and O.

Participants functioned as an expert panel within a focus group. The panel was presented with proposed features and functionalities of CLEMS. It was not expected that the participants had expertise in CLT, its underpinning model of human cognitive architecture or its corpus of evidence-based research. In the advertising for participants (Appendix H), prospective participants were informed of the need to provide responses in the form of their opinions as experienced educators.

Participants were also informed that their participation in the focus group could benefit their own professional development through increasing their knowledge of CLT and its application in teaching and learning contexts, thus bringing an educative aspect to the research, which is a principle of DBR (Brown, 1992; Herrington et al., 2007). Participants were introduced to the purpose and concept of CLEMS via a presentation and provided with reference materials and documents to clarify terminology and support the gathering of informed responses (Appendix H) by providing expanded definitions and explanations about CLT.

The information gathering form was designed to obtain feedback from participants regarding the design functions of CLEMS in three thematic areas:

1. questioning learners regarding their levels of domain knowledge and learning capability

2. questioning teachers regarding the levels of CLT strategies included in the course, program or teaching intervention they are evaluating
3. questioning teachers about the potential technical functions and capabilities of CLEMS in terms of the usefulness of these functions and capabilities within the teachers' professional contexts.

Point 3 (above) related to the usefulness and practicability of CLEMS to practitioners. This was a significant aspect of planning the design of CLEMS, since the user's experience of CLEMS would be impacted by its ease of inclusion into pressured learning environments managed by time-poor teachers. This does not denigrate the need for thorough evaluation processes which by nature are time-consuming. However, it is likely that the use of complex and time-consuming evaluation approaches could prove too onerous to be sustainable in the long term unless advanced technologies are engaged to support the process.

The completed forms, as well as handwritten responses by participants, were gathered and stored according to University of Adelaide protocols. This data was coded, collated and summarised for purposes of analysis (Appendix L). Steps were taken to ensure the validity of the research process and instruments in terms of the information being sought from the investigation within a qualitative validation paradigm (Colton & Covert, 2007). Moreover, some validation processes in use that were rejected due to their irrelevance to the study were noted.

Validation processes were implemented at a number of levels:

1. face validity: a general validation process which is defined as "the degree to which an instrument appears to be an appropriate measure for obtaining the desired information" (Colton & Covert, 2007, p. 66). Face validity was established through discussions between

the researcher and supervisors and reviewing the alignment between the specific goal of the focus groups, the type of respondents selected to participate in the focus groups and the content of the questionnaires.

2. construct validity: this category of validation represents the extent to which the instruments measure the actual constructs they purport to measure. To elaborate on this definition, constructs are "abstractions" that may not be "directly observable or measurable" (Colton & Covert, 2007, p. 66) and for this reason a process is required to verify the alignment between the measurement instrument and the measured parameters. Construct validity was built into the research process through providing clear descriptions of CLEMS in terms of its purpose and functions. In addition, the specific sub-goals expressed in the title of each focus group outcome were used to guide the information being elicited from participants. Moreover, open discussions between expert participants during the focus groups clarified points regarding the purpose of the questions. Where additional clarity was required, this was noted and collated within the raw data gathered from the focus group (Appendix L).

3. content validity: this category of validation, defined as "the degree to which an instrument is representative of the topic and process being investigated" (Colton & Covert, 2007, p. 68) focuses on specific factors that "operationalize the construct" (Colton & Covert, 2007, p. 68). Since the nature of the research project was the operationalisation of a theoretical construct, content validity formed a critical aspect of the validation process and was accomplished through the detailed specifications of the structure, content, format and useability of CLEMS.

4. multicultural validity: this is defined as the process of ascertaining the extent to which "an instrument measures what it purports to measure as understood by an audience of a particular

culture" (Colton & Covert, 2007, p. 69). The cultural relevance of the research instruments in terms of language use was validated in the forms completed by participants
during focus groups as well as asking participants to evaluate the language level to be used in CLEMS. Where lack of clarity, ambiguity of meaning or repetition was identified by focus group participants, these were recorded during the collation of raw data (Appendix L) and used to inform the language within the documents of subsequent focus groups.

In addition to the above four validation processes, triangulation between findings (Design Based Research Collective, 2003; Dick, 1997, 2000a, 2000b; Wang & Hannafin, 2005) occurred at two levels in order to ensure rigour and verify consistency between findings in terms of the development trajectory of CLEMS, as follows:

a. first, emerging data between research iterations was compared and contrasted to confirm or disconfirm findings in terms of the overall goals (develop CLEMS) as well as sub-goals (specific goals of each focus group) of the research

b. secondly, emerging findings were compared and contrasted with ongoing literature research to confirm or disconfirm findings through constant research and analysis over the three iterative cycles (Wang & Hannafin, 2005).

8.2.1 Domain knowledge

Form 1A related to gathering information about how CLEMS would be used to evaluate the prior knowledge and experience of learners engaged in a study course in order to customise or personalise learning interventions.

While the significance of prior knowledge of the subject, as well as levels of affective factors such as self-efficacy and motivation, has been extensively researched in the literature both within research on cognition (de Groot, 1965) and CLT (Sweller, 1988, 1999), some parameters remain in the early stages of research regarding their correlation to CLT. For example, the role of motivation is regarded as playing a critical role in the learner's participation in educational activities. Motivation is an emerging research direction with regard to its relationship to CLT, where it deserves more careful and deeper research studies (Atkinson & Shiffrin, 1968; Baars, Wijnia & Paas, 2017; Baddeley & Hitch, 1974; Chase & Ericsson, 1982b; Deci & Ryan, 2012; Doube, 2007; Feldon, Callan, Juth & Jeong, 2019; Hawthorne, Vella-Brodrick & Hattie, 2019; Heckhausen & Dweck, 1998; Klassen & Usher, 2010; Leppink, 2010; Martin, 2016, 2020; McCombs & Whisler, 1997; Paas, Tuovinen, van Merriënboer & Darabi, 2009; Pugh & Bergin, 2006; Ryan & Deci, 2000; Sweller, 2003). Affective or auxiliary parameters, which are classified under the umbrella term of heutagogical factors in this study, include motivation (Baars, Wijnia & Paas, 2017; Martin, 2016, 2018; Sweller, 1988) and self-efficacy (Vasile, Marhan, Singer & Stoicescu, 2011). Bandura's instruments, related to self-efficacy within a range of subject areas, have been used as the basis for evaluating self-efficacy parameters where "the efficacy belief system is not a global trait but a differentiated set of self-beliefs linked to distinct realms of functioning" (Bandura, 2006, p. 307; Bandura, 1997a, 2001).

Additional heutagogical parameters that have been identified in the literature as having a role in effective learning include self-regulation (Baars, Wijnia & Paas, 2017; Heckhausen & Dweck, 1998), metacognitive skills related to knowledge domains (de Groot, 1965), and other parameters pertinent to learner capability and readiness to learn. Metacognition has been included as one of these parameters to the extent that it related to specific knowledge domains as opposed to being viewed as a disparate skill apart from a context within a knowledge domain e.g. a learner may use the metacognitive skill of prioritisation of steps in a process, but metacognitive skills such as how to prioritise, or how to organise are not encouraged as decontextualised skills. This point cannot be overemphasised since the identified research into the acquisition of expertise in which CLT is situated has established the theoretical rationale and evidence base for contextualised learning within specific knowledge domains (Amirault & Branson, 2006; Chi et al., 1989; Clark, 2008a; 2008b de Groot, 1965).

8.2.2 Results and Discussion

Table 8.1 shows the results of the focus group. Participants rated the functions and characteristics of CLEMS related to the prior knowledge and heutagogical capabilities of the learner very highly. The responses highlighted the need for the teacher to understand the prior knowledge and capability of learners both in terms of domain-specific knowledge and heutagogical capabilities.

Table 8.1 Summary of responses by Focus Group 1 participants to Form 1A

Summary of Form 1A Responses		
No.	**Learner Profile Parameters**	**Rated Importance (%)**
1	Prior knowledge	100
2	Metacognitive skills	100
3	General self-efficacy	100
4	Digital self-efficacy	100
5	Time-management self- efficacy	93
6	Motivation – internal	100
7	Motivation – external	93
8	Time since formal learning	100
9	Proficiency in language of instruction	100
10	Social learning self-efficacy	100

Notes: Participants rated the importance of parameters related to Learner Profiles for inclusion in CLEMS (Appendix L for full record of responses by participants). These parameters represent the information that will be input into CLEMS so that the teacher may use it to inform more comprehensive, individualised learning design interventions.

The open-ended feedback responses from Focus Group 1 were coded into five key categories (Appendix L) as per points 1–5 below:

1. Theory (Th): responses relating to theoretical aspects of CLEMS
2. Technical and Systemic (T&S): responses relating to technical functions of CLEMS
3. Content and information (C&I): responses relating to content and information within CLEMS
4. Teacher (T): responses relating to the role and functions of the teacher
5. Learner (L): responses relating to the role and functions of the learner.

Points 1–10 (below) summarise and discuss key points from participant responses. Where an individual response by a participant is quoted, single quotation marks are used as a convention here and throughout the study.

1. Determining the prior knowledge of the learner is pivotal to the learning process. Because of this, teacher interviews with individual learners would be required since learners may not know what they don't know about learning processes. Different [learning design] techniques would need to be used for novices and advanced learners.

   This requirement raises the issue of how the prior knowledge of large cohorts of learners might be determined echoing the original conundrum articulated by Bloom (1984) about delivering high quality teaching at scale; a point that evokes the theme of personalisation of learning and the problem of the prohibitively high resource costs associated with providing personal tutoring for every learner. CLT does support the quest for managing large student cohorts, for example through the use of "rapid assessment methods"

(Kalyuga, 2009b, pp. 86, 89, 93, 272; cf. Falmagne, Cosyn, Doignon & Thiery, 1999–Knowledge state of learners)

To support teachers in creating individualised learning interventions, tools were developed based on a synthesis of research and emergent data (Chapter 10, Appendix F) e.g. the Knowledge/Heutagogy Quadrant (see Figure 10.16) is an aid to classifying learners into four groups according to their prior knowledge and heutagogical capabilities and needs in order to assign appropriately supported learning interventions within flexible time frames. The identification of high knowledge and high capability learners also supports teachers is selecting learners who can provide peer support to other learners Additional paper-based tools for teachers to use in discussion with learners (Chapter 10, Appendix F) also emerged to support the implementation of the 3-stage model consisting of Diagnostic Conversations (DCs), design of interventions termed Nodes of Expertise (NOEs) and Validation Conversations (VCs) to determine the learner's progress resulting from the NOE intervention (Figure 6.6). This 3-stage model contributes to improved efficiency in managing large learner cohorts by enabling rapid assessment of learner knowledge and capability, as well as identifying specific barriers to learning that require targeted pedagogical interventions. This issue is further discussed in Chapter 11.

2. Learners need to be educated into understanding reflective learning processes (Bjork, Dunlosky & Kornell, 2013; Eitel, Bender & Renkl, 2020).
3. Self-efficacy has challenges in terms of evaluation, but is essential to learning design and 'may reflect the student's barriers to learning such as fear'. This perspective aligns with the literature (Rymer, 2017).
4. The learner's digital self-efficacy is critical as 'students often have the wrong idea about

their own digital literacy'

5. Learner time-management self-efficacy is critical as 'learners may have the wrong idea of their own capabilities, but may be difficult to measure'. Further research is required to establish the link between this parameter and learning outcomes which suggests that CLEMS should include a function for supporting learners in the time taken to master NOE.
6. The internal level of learner motivation would affect all other learning outcomes, but may be challenging to measure. CLEMS could suggest strategies for addressing motivational issues, which will be 'variable and situational'.
7. External motivation may be out of the teacher's capability to influence and a challenging parameter about which to collect information, as summarised in the participant response that 'some students may not share this with you'.
8. Understanding the time since learners were previously engaged in formal learning is regarded as significant and a factor that 'learning design will take care of'. This points to the need to include this parameter in the evaluation of learner skills and capabilities prior to enrolling in courses of study.
9. Proficiency in the language of instruction was regarded as an important but difficult to measure parameter as 'Students overestimate their abilities…. Moreover, home language and cultural considerations should also be considered in conjunction with this parameter'.
10. Social learning self-efficacy was regarded as very important as most learning occurs informally through learners engaging in external activities, 'hobbies, interests and sports'. Learner-centric methodologies such as PBL task-based learning (TBL) and case-based learning can contribute to this factor (cf. Clark, 2009).

In summary, this stage of the research revealed that a focused questionnaire and personal discussion between the teacher and learner would be necessary to record the required level of formation of the learner's prior knowledge and heutagogical capability levels.. This point was regarded as an essential process in the design of CLEMS. Moreover, the responses imply that learners also require mediation in the form of educational interventions in order to gain a clear understanding of each of the parameters included in the unit i.e. learners require elucidation on the meaning and importance of their own prior knowledge or self-efficacy levels in learning. This affirms that time needs to be scheduled for DC and the teacher may require additional resources to assist in conducting these conversations learners as efficiently as possible in order to elicit in-depth information from learners about their level of domain knowledge and heutagogical capability.

8.3 Inclusion of parameters related to the learning environment

The second form was designed to elicit information regarding the inclusion of parameters related to the designed learning environment including CLT effects and strategies. It included parameters that represent the support of learners at heutagogical levels i.e. skills that may lack conclusive findings from RCT experiments that link them directly to schema formation and automation, but which are recognised as exerting an impact on the effectiveness of learning. The range of parameters included was an indication of the complex range of possible learning interventions that require consideration in the construction of learning environments.

The implementation of CLEMS and its effective use for managing large cohorts of learners might arguably be one of the most important issues to address in implementing CLEMS in large educational institutions.

Feedback indicated a high acceptance level for all of the listed learning interventions to be included in CLEMS for evaluation within learning environments (Table 8.2).

Table 8.2 Summary of responses by 15 participants in Focus Group 1 to Form 1B, ordered according to the questions on Form 1B.

Summary of Form 1B Responses		
No.	**Designed Learning Intervention Factors**	**Rated Importance (%)**
1	Link to prior knowledge	87
2	Pre-/post- tests	93
3	Rapid evaluation	93
4	Learning outcomes	87
5	Real-life context (learning environments)	100
6	Learner control	93
7	Social presence	87
8	Schematic organisation of materials	87
9	Material organised into higher level chunks	93
10	Presenting concepts before knowledge	100
11	Using worked, faded and *unassisted problems	100
12	Using the self-explanation effect	93
13	Using schema-validation skills	100
14	Using the imagination effect	87
15	Emotional engagement of learners	93
16	Expert guidance available to learners	93
17	Flexible time facilitated for individual learners	93
18	Using goal-free examples	93
19	Reducing split-attention in learning material	80
20	Removing redundancy in learning materials	87
21	Means–ends analysis avoided in learning interventions	87
22	Unsupported learning avoided	87
23	Modality effect used	87
24	Risk levels considered in learning goals	87

Notes: This table specifies possible factors for inclusion in designed learning environments, including principles, effects and strategies arising from CLT (see Appendix L for Raw Data, Form 1B).

*Unassisted problems refer to traditional problems where scaffolding is not provided to assist learner in the problem-solving process. Sweller, Ayres and Kalyuga (2011, p. 106) call this "full problem solving".

These responses suggest that while CLEMS could provide the capability of recommending specific interventions based on learner profile analyses (Lu, 2004), the teacher's role would need to remain central in adapting the chosen intervention to the specific needs of the learner. This confirmed the mediative–adaptive characteristic of CLEMS, where the centrality of the teacher's role as expert, advisor and mentor (Bond, 1999; Howlin & Lynch, 2014; Nash & Shaffer, 2010) would be necessary for successful use.

The mediative–adaptive approach suggested for CLEMS therefore places the role of technology as an enabling function as opposed to a controlling function. It appears plausible, given the broad range of possible interventions, that one new intervention at a time, decided by the teacher who has insight into the learner's knowledge and heutagogical capability levels, might be the most beneficial application of CLEMS for individual learners. The introduction of one new intervention at a time aligns with the narrow limits of change principle at a theoretical level, which is one of the principles underpinning human cognitive architecture. In addition, the necessity for slowly-occurring, incremental change to schemas at a deep level during learning echoes the notion of kaizen as a pedagogical strategy (Khayum, 2017; Suarez-Barraza, & Rodriguez-Gonzalez, 2015), in which time is adjusted to facilitate deep changes to schemas according to the narrow limits of change principle (cf. Bloom, 1968; Sweller, Ayres & Kalyuga, 2011, p. 40).

Finally, it is noted that in Form 1B, complete, traditional examples were referred to using the term "full examples" (Sweller, Ayres & Kalyuga, 2011, p. 106) indicating that learners were required to complete every step of the problem-solving process without the aid of scaffolding in contrast with completion problems where scaffolding is faded and learners are required to do increasingly higher numbers of problem-solving steps.

8.3.1 Discussion of responses to Form 1B

Participants provided additional comments that supported the interpretation of the rating scores in the questionnaires. These additional responses are summarised and discussed in points 1–24 below, where single quotation marks are used for direct quotes by participants.

1. Linking learning activities to prior knowledge was regarded as important for informing the “scaffolding of knowledge” and building on existing learning. However, the method of achieving this linking process requires careful consideration in terms of practice.

2. The impact of pre- and post-tests require monitoring for impact on learning. In addition, the question was raised as to whether pre- and post-diagnostic tests could be standardised.

3. Rapid evaluation techniques were reflected as providing the basis for branching to remediate learning. The fairness of rapid evaluation techniques was questioned; this may have been due to lack of clarity as to the purpose and function of rapid evaluation techniques by participants, suggesting the need for further investigation into the use of this technique as well as the requirement for it to be implemented in a systematic and supported way.

4. The inclusion of learning outcomes was noted as an important and routine part of courses, as that is a regulatory aspect of teaching (for example, in the vocational education and training sector) (cf. Australian Skills Quality Authority, 2017; cf. Australian Society for Evidence-Based Teaching, 2017). In addition, constructive alignment (Biggs & Tang, 2011) was observed as an essential part of the pedagogical process to support learning outcomes. It was questioned whether or not learners read or understood outcomes, reflecting a possible need to

manage this process more effectively by teachers. The discussion points regarding learning outcomes affirmed the need for an initial in-depth conversation between teachers and individual learners as expressed in the DC.

5. The real-life context of teaching was observed to provide meaning and motivation to learners as well as being ‘very important for professional learning’. However, the timing of introduction of this model of learning was noted as being critical. These responses reflect the need to include heutagogical factors in learning design, with authentic learning contexts supporting these and other affective factors that exert an influence in learning environments. In addition, the role of the teacher in selecting the appropriate time for introducing real-life learning contexts was observed to be a key factor in mediative–adaptive pedagogies
The inclusion of authentic learning environments and contexts are complex by nature, imposing high intrinsic cognitive loads on learners. Therefore, specific learning design strategies are required to ensure that sub-parts of the intended learning materials and processes are taught and practiced by learners to the point of automation before they are integrated into higher-level knowledge chunks or clusters. This learning design strategy supports learners in assimilating complex information (Pollock, Chandler & Sweller, 2002).

6. Learner control in learning was noted to have ‘strong ties with building self-efficacy’ reflecting a heutagogical aspect of pedagogy that should be ‘a matter of course’ in teaching. It was also observed that learners need to be able to pace their own learning and go back over or identify concepts they don’t understand, implying the need to develop both the heutagogical capability and domain-specific knowledge of learners.

7. The need for social presence was reflected as being dependent upon the nature of the learning environment, but not necessarily a factor ‘required for learning to occur’. It ‘may impact motivation and improve learning’ for some students, but should not be assumed for all students. Social presence may be seen negatively as ‘social pressure’ that may not be required for learners to succeed in learning; moreover, social learning was noted to be dependent on the course or subject and is ‘very important in professional specific learning’. Responses indicate the varying usefulness of social presence in learning environments, signifying that its specific inclusion would require consideration of the particular learning context in order “to reduce the learner’s cognitive load, freeing the learner to engage in active cognitive processing” (Mayer, 2005, p. 346).

8. The schematic organisation of materials by the deliberate separation of learning materials into schemas based on higher level organisation principles and domain-specific knowledge was regarded as useful only with the use of worked examples to demonstrate the use of schemas (Anderson, 1984). The separation of organising principles and content knowledge was noted as routine in courses for one respondent. This factor points to the need to structure curriculum to align with human cognitive architecture, where the logical organisation of domain knowledge is deliberately nested within higher organisation principles to unify knowledge into well-organised schema structures.

9. The organisation of learning materials into higher-level chunks was noted as being dependent on the capability of the learner in terms of Bloom’s taxonomy. This point emphasises the mediative–adaptive role of the teacher in learning design, which can occur

through the teacher's familiarity with the learner's prior knowledge and heutagogical capability. For example, the higher levels of Bloom's Taxonomy can only be operationalised if there are sufficient lower levels of knowledge to support the higher levels (Bloom et al., 1956).

10. Teaching conceptual structures before detailed knowledge would depend on the subject being taught and learned. This reinforced the need for a mediative–adaptive role of the teacher in adapting learning to the needs of the learner.

11. The incorporation of the sequence of worked examples, completion problems and traditionally formatted tasks or problems (where learners solve every step unassisted) into the pedagogy was noted as allowing 'the student to identify their own problems in learning and *reset* learning'. This response suggests that well-scaffolded learning supports both the development of domain knowledge and heutagogical capability in the learner. The sequence of worked examples, completion problems with faded support or scaffolding and traditionally formatted tasks or problems where learners completed every problem step does not represent a rigid pedagogical process, but may be flexibly applied depending on the needs of learners i.e. the principle of personalisation in applying this strategy needs to be considered in every case (Sweller, Ayres & Kalyuga, 2011, p. 106).

12. Self-explanation was acknowledged as a strategy for strengthening learning effects, which aligns with the findings of key researchers into self-explanations as a pedagogical strategy (Chi, de Leeuw, Chiu & LaVancher, 1994). It was noted that self-explanation may be

complemented by the strategy of explaining to others i.e. learners teaching others as a learning strategy. However, self-explanation as a strategy may be limited in cases where the learner's English levels are not sufficiently strong. This points to the need for the teacher to have a clear idea of learner capabilities in order to tailor teaching interventions to the needs of the individual learner rather than assuming the effectiveness of strategies without regard for learner needs. While self-explanations are strongly validated in the research base, there is a clear differentiation between the effectiveness of self-explanation and explanation to others with different learning effects for each one; moreover, self-explanations can vary in quality, either representing surface knowledge such as repetition of facts, or deep knowledge such as meaningful links and connections that enable the transfer of knowledge to anisomorphic situations i.e. the far transfer of knowledge.

13. The use of schema-validation skills by learners was unanimously agreed as a significant parameter of the learning environment, affirming the use of VCs as conceptualised in Figure 6.6.

14. The strategy of engaging the learner's imagination was regarded as presenting challenges if used prior to the commencement of a course. In addition, the engagement of the imagination of learners would be dependent on the nature of the course being taught. However, it was also observed that due to its value, one would 'hope that this was happening by default'. The assumption that the imagination of learners would be engaged by default requires further investigation.

15. The engagement of imagination as a pedagogical strategy is an emergent research direction in CLT but its use limited to learners who have attained a sufficient base of prior knowledge (Sweller, Ayres & Kalyuga, 2011, p. 192). Emotional engagement was noted as an ‘extremely important’ factor for establishing long-term memories. This was also emphasised as a key factor in ‘professional learning’.

The links between emotional, or affective, aspects of learning, while generally acknowledged as significant in the learning process, represent a key research direction in terms of their specific effects on cognitive load (Deci & Ryan, 2012; Doube, 2007; Heckhausen & Dweck, 1998; Klassen & Usher, 2010; LeDoux, 2013; Leppink, 2010; Martin, 2016; Martin & Evans, 2020; Paas, Tuovinen, van Merriënboer & Darabi, 2009).

16. The availability of expert guidance was not regarded as a critical factor in learning. This concurs with the view that for novices, highly structured learning should be the norm until the learner is able to exercise self-determined learning capabilities i.e. there needs to be gradual reduction in guidance as expertise increases (Sweller, Ayers and Kalyuga, 2011).

17. Flexible learning delivery time was affirmed as a method of supporting different levels of need in terms of learning goals. In addition, a flexible approach to learning would give insight into the value of other interventions. It is noted that flexibility can have different meanings and it is therefore important to define more precisely how this is practiced in different learning environments. If a pure mastery learning model is implemented, then institutions would need to provide learning time frames according to learner needs.

Unless institutional policies allow a true alignment of time flexibility with learner needs, what is termed flexible learning may in fact more realistically be termed limited flexible learning.

18. Goal-free problem solving examples were rated highly as an intervention strategy, but the use of this strategy would have to be used judiciously with regard to summative or formative learning. This strategy was also observed to facilitate stress reduction in learners. In future studies, the reduction of stress through the use of goal-free problems, as well as other CLT strategies, might be a positive research direction.

19. Recognition of the importance of split-attention in learning design was strongly affirmed by participants. However, it was observed that many instances in both print and online learning modules exist where the principle is not taken into account. Identifying where split-attention occurs in learning materials is a potentially straightforward strategy for aligning learning design with the structure and functions of human cognitive architecture; this is due to the fact that learning materials can be reviewed in terms of this parameter outside of course delivery i.e. the relative level of integration of graphic and textual information to ensure spatial contiguity, and the relative level of synchronicity between visual and audio information to ensure temporal contiguity and avoidance of split-attention for high element interactivity learning materials (Mayer, 2005; Sweller, Ayres & Kalyuga, 2011, p. 121).

20. Removing redundancy in learning materials was strongly rated as a significant parameter in learning environments.

21. The avoidance of means–ends analysis in learning interventions was strongly supported as a parameter in learning environments in order to build the knowledge schemas of learners.

22. Unsupported or unguided learning i.e. where novice learners are left to discover information and concepts without direct guidance, was noted to be important, therefore pointing to the need for the teacher knowing which learners require support. This points to the need for a more comprehensive and details view of learners' prior knowledge and progress in terms of advancement towards expertise. The teacher's knowledge of this point is critical, as learners may flounder (Clark, 2013) in their progress when they encounter barriers to learning (Land, 2014) if supported learning is not available, or available but inappropriate for the needs of the individual learner. This point references Vygotsky's more knowledgeable other and zone of proximal development and the worked example effect (Sweller, Ayres & Kalyuga, 2011).

23. The use of the was modality effect was strongly supported as a parameter in learning environments to manage cognitive load though the appropriate engagement of audio and visual channels in working memory.

24. Risks associated with learning were defined in terms of hazardous environments as well as emotional risk to learners due to high levels of stress associated with exams. In addition, consideration would need to be given to mitigation of risk 'to avoid litigious situations'.

8.4 Summary of responses to Form 1B

Results suggest the inclusion of all of the proposed intervention parameters within CLEMS. However, some key caveats and cautionary points were noted in the feedback from participants. These points emphasised the need to consider the knowledge and heutagogical profiles of individual learners. A high level of affirmation was indicated in terms of including affective and social dimensions of learning in tandem with strategic interventions arising from CLT.

Overall, these responses emphasised the central role of the teacher in determining the appropriate level of intervention for individual learners, i.e. affirming the mediative–adaptive role of teachers in taking the full spectrum of individual learner needs into account when devising learning interventions. In other words, while a software system might recommend an evidence-based strategy for a particular learner profile, its application will always need to be based on the teacher's judgement regarding the individual learner's prior knowledge and heutagogical capabilities.

This emergent finding aligns with evidence-based medical practice references in the literature review, where the practitioner may use digital tools to diagnose states of health, but the prescription for treatment always falls back on the judgement of the practitioner. Moreover, the medical practice of taking a history of each patient as an individual also aligns with the feedback from the focus group regarding education i.e. a strongly stated position that establishes the centrality and value of the teacher as the educational expert. The implications of these emergent findings are that while teachers are required to be more specific in their diagnoses of individual learner needs, they do not have an equivalent set of instruments that medical practitioners use to diagnose states of health e.g. thermometers, x-ray machines and other instruments. This points to the need for teachers to be better equipped and resourced to analyse problems with learners, diagnose or anticipate issues such as barriers to learning and have access to systems that record and monitor progress over the learner's career at the institution and beyond.

To this point in the discussion of results from focus group 1, the functions of CLEMS have been considered in terms of individual learners. In an alternative application of CLEMS, an existing course may be analysed prior to being run for students in order to align it with some or all of the intervention strategies. This reflects a dual application of CLEMS: the advancement of individual learners towards higher levels of expertise, as well as the alignment of existing courses with evidence-based strategies arising from CLT.

8.5 Participant feedback forms used in Focus Group 1C

A feedback form was used to elicit information regarding the inclusion of parameters related to general functions, technical capabilities and characteristics of CLEMS (Table 8.3).

8.5.1 Responses to Form 1C – Instrument functions/characteristics/capabilities

Table 8.3 Summary of responses to Form 1C

Summary of Form 1C Responses		
No.	**Instrument functions/characteristics/capabilities**	**Rated Importance (%)**
1	Linked to a theoretical model	72
2	Facilitate consideration of learner profile (Form 1A)	72
3	Learning program profile (Form 1B)	72
4	Teacher-selected evaluation parameters	72
5	Provide recommended intervention strategies	72
6	Record intervention strategies	72
7	Sustainable through community ownership	72
8	Extensible/adaptable to include additional parameters	72
9	Teacher (vs. system) administered	72
10	Database driven	72
11	Rapid deployment	72
12	Cloud based	72
13	App format	72
14	Store/track data	72
15	Visualised data output	72
16	Textual data output	72
17	Experiment based	72
18	Educative for users	72

Notes**:** This table specifies the relevance of design functions, characteristics and capabilities of CLEMS (see Appendix H for Raw Data, Form 1C).

In the rating responses provided by the 15 participants in Focus Group 1, all parameters (1–18) received a very high relevance rate of 72%; in addition, a rich range of comments were also provided that supported the interpretation of the rating scores provided by participants. These are summarised and discussed below.

1. The need for CLEMS to be based on a theoretical model reflected the need for educational decisions regarding learning design to be informed by research.
2. Consideration of the learner's profile in terms of prior knowledge levels reflected the need to personalise learning through an adaptive model i.e. by designing new learning interventions with a view to building on the learner's prior knowledge.

3. The profile of learning programs was considered a high priority in terms of the level of evidence-based practices which they contained. This suggests that CLEMS would have two separate functions thus providing evaluation choices for educators depending on their needs. First, the evaluation of the learner's prior knowledge and heutagogical capability in order to adapt new learning interventions with these levels; secondly, the evaluation of learning programs for the level of evidence-based practices they contain.
4. The ability of the teacher to select parameters for evaluation was rated as important, but institutional policies might play a role in determining the extent to which teachers can determine their own evaluations. In addition, this factor may be important in "practice-based disciplines". These participant responses affirm the autonomy that teachers require in managing their own evaluations of learners, but also point to policy level negotiations that

may be required to provide teachers with a level of independence in creating and setting learning interventions.

5. The recommender function of CLEMS to provide suggested intervention strategies and examples of their application to teachers was considered a key characteristic of the functions of CLEMS. The high rating of this parameter, in addition to positive written responses for its inclusion, reflects the need for teachers to have easy and unobstructed access to a database of evidence-based learning strategies and exemplars of their application. Teachers could access knowledge then exercise their judgement in applying it when devising specific learning interventions.

6. The capability of CLEMS to record intervention strategies was highly rated. This function reflects the raison d'être of CLEMS in terms of continuous improvement of learning interventions (Mastin, 2009). The capability to record, report and modify interventions is therefore the core functionality on which all other functions are built, with the recorded interventions and their learning outcomes being used to inform or modify future interventions, identify trends and measure the relative success of different intervention strategies.

7. The community ownership of CLEMS was rated as critically important for its use and sustainability, but the financial implications of this scenario would require consideration. This highlights a salient point for the future development of CLEMS beyond the current study, which would require further research regarding its potential use and usefulness in the broader community, how it would be funded and how its ongoing sustainability would be maintained.

The open source model espoused by MOODLE (2012) suggests a possible method for making CLEMS available to the wider educational community.

8. The flexibility of the CLEMS framework for enabling extensibility to add new features and functions was highly rated, with additional considerations related to possible types of extensions and the capability of incorporating future research into existing structures. Areas of extensibility could include social media, integration with other systems e.g. student management systems (SMS), learning management systems (LMS) and new evidence-based strategies that emerge from CLT research.

9. The operation and control of CLEMS by teachers was considered a key function, enabling interventions to originate at a grassroots level. This aligns with the original intent of CLEMS as a mediative–adaptive system i.e. supporting adaptive learning interventions, but controlled through the judgement of the teacher in terms of how interventions are structured and implemented (Webley, 2013).

10. The database-driven functionality of CLEMS was considered important in order to track interventions and their effects through meta-tagging as well as to record teacher feedback. Extending database-driven functionalities would also enable long-term tracking of learner progress and modifications to programs or courses over extended time periods.

11. The rapid deployment capability of CLEMS was considered a critical factor in its adoption and use. Rapid deployment, tracking and management of learning interventions

would need to form a key part of CLEMS. Rapid deployment would be enabled through database-driven technologies and analytic reporting. In terms of actual use, CLEMS would be envisioned to facilitate a learner or course analysis in a short time period to avoid its use imposing an additional time burden on teachers that did not provide value for the effort expended (see Behling, 2012–Burden of learning).

12. CLEMS features of being cloud based, universally available and scalable were affirmed and highly rated. In addition, the universality of the application to all platforms and devices was also noted as significant. These architectural factors relate to the usefulness and useability of CLEMS. Ongoing research would be required to ensure that the user experience remained simple and functional while harnessing the capabilities of advanced technologies and delivery methods.

13. The app format of CLEMS was affirmed as useful for on-the-fly analysis by teachers, use on mobile devices and desktop devices. The cross-platform accessibility of CLEMS appeared to be a factor that would enhance the usability of CLEMS. It is noted that due to time and financial restraints, the prototype instrument of this study was developed on a cloud based platform using a desktop application. At a future stage of development, the desktop functions could be reproduced within a mobile application subject to obtaining further development funding.

14. The storage of student information (data) for future use was rated as important, provided all security and privacy protocols are observed. In addition, levels of access and

authentication would need to be guided by rigorous policies, as would sharing of data between institutions.

In terms of the ongoing uses for the data gathered in CLEMS, future directions might include long-term tracking of students in terms of mastery of chunks of knowledge. This means greater transparency of learner progress in order to provide early interventions where required. While beyond the scope of the current study, CLEMS could potentially be used to track learner skills and heutagogical capability across the divide from high school into higher education in order to ensure a seamless transfer into higher education. These and other issues related to the mining of data for trends and best practices are likely to remain high on the development agenda of CLEMS in future.

15. The visualisation of data reports was affirmed as a useful function of CLEMS "for ease of use" analysis and processing of data. The intention behind graphic output is to provide teachers with the information required to inform decisions regarding learning design. For example, relative strengths and weaknesses of pedagogical practice could be shown in a traffic light system to reflect high risk (red), medium risk (amber) and low risk (green) in terms of meeting the needs of learners. Visualisation is effectively part of the rapid deployment and ease of use functionalities required to support teachers as they implement evidence-based interventions within complex in situ teaching environments.

16. While the experiment-based characteristic received a high rating as a necessity in CLEMS the written feedback demonstrated some lack of understanding of the concept. The

experimental nature of CLEMS means that it is designed for teachers to run in situ experiments in class to validate the relative strengths of interventions. The CLEMS database will be populated with searchable strategies and exemplars for teachers to use for meeting the needs of learners based on the responses learners give to evaluation questions i.e. the recommender function of CLEMS.

17. The experimental nature of CLEMS means that these interventions and the circumstances in which they are implemented will need to be evaluated for their relative effectiveness. The time required to run experiments was mentioned as a potential risk factor, so experiments would need to be created and deployed quickly in order to avoid additional stress on teachers and learners. Depending on the type of experiment, the teacher might implement one or many, small or large, simple or complex experiments in a year. Single-variable interventions might be the most reliable way of managing the process in terms of linking interventions to outcomes, but the mediative–adaptive nature of CLEMS means that teachers would have the choice in the chosen approaches. The question regarding interventions being experiment-based received a high score. The experimental nature of CLEMS is a core characteristic that supports measuring and monitoring the effectiveness of interventions, for example by using different interventions on different cohort groups (Brown, 1992); supporting adaptive learning; identifying useful and effective strategies at for inclusion in future interventions; facilitating reflection on the outcomes of interventions by teachers individually or as shared reflection between teaching communities; and facilitating a scholarly approach to teaching that promotes the continuous improvement of evidence-based practice (Hempenstall, 2006; Waring & Evans, 2015). Overall, this approach is congruent with the use of learning analytics

for supporting the scholarship of teaching and learning (Kiener, 2009); in this view, the disruptive potential of learning analytics “lies in the possibility it provides to illuminate, in an evidence-based and data-driven manner, how the learning and teaching process works in practice” (Bronnimann, West, Huijser & Heath, 2018, p. 353).

18. The educative aspect of CLEMS elicited some positive and cautionary feedback. A possible risk of introducing new technologies included the teacher’s required time commitment to using it effectively. In addition, the nature of CLEMS would mean that teachers would also be novice learners on the path to mastery in using CLEMS and gaining a deep understanding of the effects and strategies arising from CLT.

8.6 Summary

Overall, the rating and written feedback responses to the first iteration reflected a high level of agreement with the proposed parameters of CLEMS in the proposed key areas. As a result, a rich source of comments and discussion points for consideration were elicited through approximately fifty written responses for reflection in addition to the rating of suggested parameters. The parameters related to the three key areas of learner profiles, learning interventions and technical functions of CLEMS, providing useful cautionary notes and caveats related to the development of CLEMS.

The feedback affirmed the role of the teacher as being in control of CLEMS to serve individualised, educational purposes rather than being used as a system which controls the teaching environment in an impersonal way. While the aim of this research iteration and focus group was to validate and critique the proposed design parameters of CLEMS, the number of responses for consideration suggested that CLEMS could be advanced further through future research iterations beyond the current study.

In addition to clarifying content and function regarding CLEMS, the responses also brought key theoretical aspects of learning to the fore. These included the need to incorporate heutagogical and affective factors to a greater level of prominence as influential factors in learning environments, therefore suggesting a more holistic educational model being administered through the functionality of CLEMS.

It was noted that connections between heutagogical factors and cognitive load are still in a nascent state in terms of research, therefore where direct evidence is not available, these factors would be regarded as relevant to the extent that they support schema automation. For example, factors such as motivation, learner agency (Klemenčič, 2017), self-efficacy, mindset and other factors should be consciously included in learning interventions to the extent that they support the growth of learners towards expertise (Knowles, 1975).

The feedback regarding the design of CLEMS in terms of its features and functions, as well as the additional comments and insights provided by participants, provided sufficient data to advance the development of CLEMS to the next iteration, in which a theoretical proof of concept of CLEMS was developed, presented and evaluated.

Chapter 9: Second Data Chapter - Evaluating a Proof of Concept of CLEMS

Research Iteration 2 and Focus Group 2

9.1 Introduction

The previous chapter (Chapter 8) provided an outline of the first research iteration, which concluded with Focus Group 1. The aim of Focus Group 1 was to advance the theoretical model of CLEMS into a set of specifications that could be used to develop a prototype.

The data from Focus Group 1 confirmed that it had achieved its intended goal of ratifying the design of CLEMS in terms of the following parameters:

1. the profile of learners
2. the evaluation standard adopted for use in CLEMS
3. the technical functions of CLEMS in terms of advancing learners towards higher levels of expertise in specific knowledge domain.

The results from Focus Group 1 signified that the research process was ready to advance to the second research iteration, titled "Evaluating a proof of concept of CLEMS". The goal of this iteration was to develop a proof of concept of CLEMS that would be presented to participants for critique and validation in the second focus group. The raw data and resources that were used in Focus Group 2 are contained in Appendix J.

9.2 Research timeline

Figure 9.1 below provides details of the time frame and contents of the second research iteration.

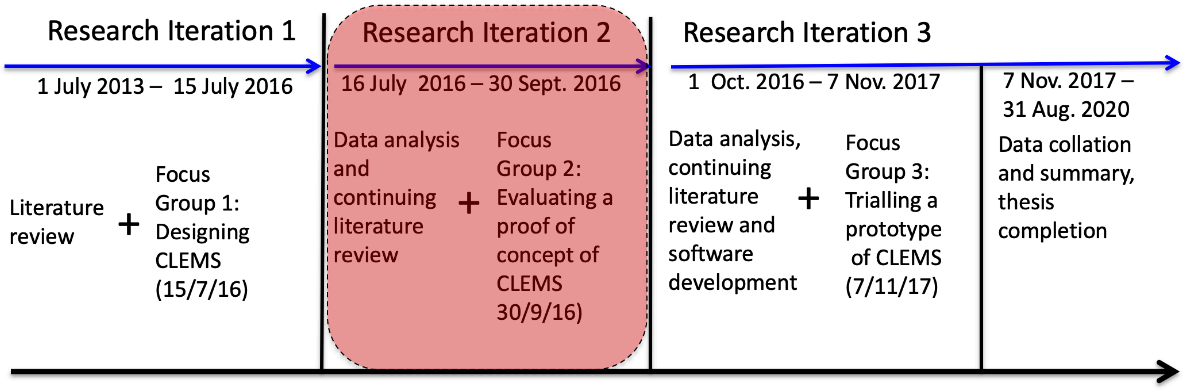


Figure 9.1 Research overview with Research Iteration 2 highlighted

The second research iteration ran for just under six weeks until 30 September 2016, on which date the second focus group was conducted. This time span was sufficient to initiate investigations of potential software design processes for creating the software instrument prototype with the emerging functionalities from the theoretical model (Chapter 6) and findings from Focus Group 1.

During Focus Group 2, a similar process was used as in Focus Group 1 (Appendix M) and The focus group reflected the cyclical, design-based research model by Reeves (2006). Information to prepare participants for the focus group was made available at the web address www.elearningdesignphd.com, a temporary Moodle site which was also used as a repository for the information and forms required by participants e.g. consent forms, complaints procedures and supporting information forms.

9.3 Focus Group 2: Aim and outline

The second focus group was titled "Evaluating a proof of concept of CLEMS". The data-gathering instruments and questionnaires (Appendix N) were designed to elicit responses from participants who were experienced educators based at the University of Adelaide and other higher educational institutions. Techniques used included brainstorming, questioning, discussion and written responses. All University of Adelaide research ethics protocols were observed and participants were provided with a full set of required forms to complete (Appendix N). In addition, participants were provided with contextual and reference information regarding the background to the study, progress to date, and information to inform and guide the brainstorming aspect of the focus group. A paper-based proof of concept of CLEMS was presented to participants for review and critique.

The written responses by participants, as well as field notes taken by the researcher during the focus group, were gathered and stored according to study protocols. This data was coded, collated and summarised according to defined protocols.

The data was compared between the first and second iterations in order to reflect on the progression of the design from theoretical model to graphic representations of a visual interface of CLEMS.

9.4 Participant Feedback from Focus Group 2

9.4.1 Introduction

Focus Group 2 consisted of a smaller participant group than Focus Group 1, with six participants. This focus group was titled Evaluating a proof of concept of CLEMS and was scheduled from 12.00 pm to 1.30 pm on 30/9/16 in the School of Education. The roles and numbers were as follows: Senior Lecturers (3), Academics (2) and Instructional Designer (1). The level of expertise on the panel of participants was sufficient for the purposes of evaluating the proof of concept of the CLEMS, since it "adequately answer[ed] the research question" (Ulin, Robinson & Tolley, 2005, p. 55).

The information gathered from participants was in the form of reflective comments on the visualised proof of concept of CLEMS (Appendix J). Sixty seven useful feedback statements, reflections and probing questions were contributed by participants. This represented a high level of quality feedback from a small but highly qualified group of expert participants.

The focus group participants also raised critical questions about the theoretical basis, functionality and purpose of CLEMS, affirmed conclusions from the first focus group and contributed emergent ideas that contributed to the next stage of development of CLEMS.

9.4.2 Coding of responses from Focus Group 2

The feedback responses from Focus Group 2 were coded into key categories as per Focus Group 1, using the following coding system:

1. Theory (Th): responses relating to theoretical aspects of CLEMS

2. Technical and Systemic (T&S): responses relating to technical functions of CLEMS

3. Content and information (C&I): responses relating to content and information within CLEMS

4. Teacher (T): responses relating to the role and functions of the teacher

5. Learner (L): responses relating to the role and functions of the learner

9.5 Results and Discussion: Summarised comments and feedback from Focus Group 2 participants

The responses by each participant were summarised, with a code assigned to each response according to the above code key. Two participants provided shared comments on one response sheet; this did not represent a problem as all comments were coded and organised into themes regardless of the source.

The coding represented themes for consideration in the development of CLEMS. Where more than one code could be applied to a response, a single key code representing the most fitting code category was assigned.

Participants provided notes, bullet points or comments to supplement questions. These notes were interpreted in the context of the part of the form responded to by the participant. Themes in the responses of each individual participant were identified, with a final summary represented as a collation of all responses. Through the collated responses, the usefulness of CLEMS as well as potential weaknesses and pitfalls of CLEMS emerged for consideration in its development during the next research iteration.

9.5.1 Summary of responses by participant 1

This participant validated the presented functions of CLEMS as suitable for information-gathering, reporting and evaluation of learning design. CLEMS was noted to offer potential for differentiated learning, but might be limited to use for identifying struggling novices. In addition, the participant noted the importance of considering the benefits (or otherwise) of letting learners have access to analyses of their own strengths and weaknesses with regard to learning.

This participant focused key responses around Vygotsky's theory of social learning to represent the learning process (Appendix N), demonstrating an in-depth knowledge of this theoretical construct. Overall, a positive picture emerged regarding the usefulness of CLEMS, but caveats were highlighted regarding its application to learners at different stages of development. Of note was the emphatic need for reference to underpinning learning theory regarding the functionality of CLEMS, as well as validating the process used in its development.

9.5.2 Summary of responses by participant 2

This participant demonstrated clear understanding of CLT principles and practices and validated the presented functions of CLEMS as suitable for information-gathering, reporting and evaluation of learning design. The participant noted that the usefulness of CLEMS could be extended to assessment, feedback and reflective practice, as well as for broader applications such as informing educational policy, developing curriculum, or setting educational standards. Additional consideration in design of CLEMS could include factors such as learner resilience, metacognitive capability, teaching methods being aligned with learner preferences, aligning learning with the learner's zone of proximal development, and using CLEMS to determine levels of further personalised support for learners. CLEMS was also noted to have the potential for data mining of information that could be used for decision making in key areas of education.

Similar to participant 1, this participant framed responses around Vygotsky's theory of social learning to represent the learning process. The strong link to a theoretical framework illustrated the need to evaluate learning design in terms of an underpinning theory.

9.5.3 Summary of responses by participant 3

This participant demonstrated a deep understanding of CLT and validated the presented functions of CLEMS as suitable for information-gathering, reporting and evaluation of learning design. These responses provided references to research that could expand the basis for CLEMS by including additional concepts such as visible thinking (Collins, Brown & Hollun, 1991; Hattie, 2009, 2012; Ritchhart & Perkins, 2008) (cf. Bergeron, 2017–Critique of Hattie's methodology), threshold concepts (Land, 2014; Meyer & Land, 2003, 2006; Perkins, 2006), awareness of learners floundering in their learning progress (Clark, 2013) and initiatives such as Harvard University's Project Zero (2016).

CLEMS was observed to be another method of devising individualised education plans, but caution was recommended regarding practicalities of resourcing it due to potentially high costs. In addition, it was suggested that CLEMS may be more suitable for entire cohorts than for individual learners due to resource limitations.

9.5.4 Summary of responses by participant 4

This participant validated the functions of CLEMS as suitable for information-gathering, reporting and evaluation of learning design. It was pointed out that CLT was not the only theoretical construct on which CLEMS could be based and others may also be valid and therefore implied that alternative theoretical frameworks were worth exploring for their potential in this regard.

Considerations in the design of CLEMS that were identified included facilitating the adaptability of learning interventions to learner achievement levels, the need for mediation by the teacher, as well as the heutagogical factor of self-reflectivity of learners. It was cautioned that learners with high level schema development may not be suitable for peer level guidance of novices as they may not have deconstructed their own learning sufficiently to understand underpinning learning processes, implying the need for expert support of novice learners by trained teachers.

9.5.5 Summary of responses by participants 5 and 6 (combined)

These two participants, who combined their responses in the focus group, validated the presented functions of CLEMS as suitable for information-gathering, reporting and evaluation of learning design. Participants emphasised the significance of heutagogical functions in learning, as well as the functions of different cognitive loads, in particular the goal of achieving schema automation through increased germane cognitive load in the design of learning interventions.

Consideration was given to the use of CLEMS for individual learners vs. entire learner cohorts, and whether CLEMS could be used to stream students. The analysis of strengths and weaknesses of learning programs was seen as a positive characteristic of CLEMS.

9.6 Overall summary of responses by Focus Group 2 participants

A broad range of feedback was provided by participants in validating the functions of CLEMS and for consideration in its development. All participants validated the format and functions of CLEMS as presented in the Focus Group information sheets.

9.7 Summary of Post-Focus Group 2 evaluation by participants and next steps in the

research process

Overall, the functions of CLEMS were validated as suitable for gathering information from learners and teachers to inform the design of learning interventions, setting individualised goals that incorporated CLT strategies, and reporting on learner progress towards expertise in specific knowledge domains.

In terms of the usefulness of CLEMS, a lower rating was obtained than Focus Group 1 for the post-focus group evaluation. This may be explained by the complex nature of CLEMS attempting to be conveyed through a paper-based proof of concept, where some participants expressed a desire “to see CLEMS”. As functions of CLEMS were portrayed on separate pages of printed handouts, this could have imposed a high cognitive load on the working memory of participants in the form of split-attention. This could have been mitigated using an online version with hyperlinks and should be considered in future research iterations, or in replicating this study, provided that necessary caution is taken to ensure that split-attention is not invoked.

Notwithstanding this limitation, feedback reflected that participants understood the overall functions and characteristics of CLEMS and positively affirmed their usefulness. In addition, a broad variety of additional responses was provided by participants for informing and enriching the next stage of development of CLEMS.

Focus Group 2 validated the proof of concept of CLEMS at both a functional level (input fields for learner and teacher; analytic reporting capabilities) and content level (CLT effects and heutagogical factors). The results of this focus group represented a significant step forward in the development cycle of CLEMS, since it was the first visualisation of the theoretical model in terms of user experience for teachers and learners.

Additional theoretical considerations were suggested as the main focus of the CLEMS, including Vygotsky's social learning theory and Meyer and Land's threshold concept theory, implying that CLT could be enriched by one of these theories as a future research direction (Tuovinen, 2005). Alternatively, theoretical frameworks might be combined or synthesised to add value to the theoretical foundation of the study. The expertise model of learning assumed for CLEMS was validated, where learners could be evaluated for their relative levels of formation and automation of schemas, as shown by their capability in demonstrating expertise, where expertise is defined in alignment with the CLT model as the immediate recognition of problem types as well as the rules governing their resolution.

The expanded use of CLEMS for data-mining and informing policy was noted as a valued affirmation of its systemic capabilities. Overall, the monitoring of the learner's progress in terms of both domain knowledge and heutagogical capability was validated, as was the use of CLEMS for both individual and cohort evaluation. Moreover, the extensibility of CLEMS to include additional heutagogical factors such as learner resilience and metacognitive skills was noted. It has been observed that the extent to which heutagogical factors such as motivation and self-efficacy align with cognitive load continue to be validated through additional research. In terms of this study, heutagogical factors, of which motivation and self-efficacy are examples, are included in CLEMS to the extent that they support schema formation and automation.

Figure 9.2 provides a simplified flow diagram representing the functional model of CLEMS that was consolidated through Focus Group 2 for advancing its development into the next iteration. This model aligns with the key functions of the theoretical model proposed in Chapter 6:

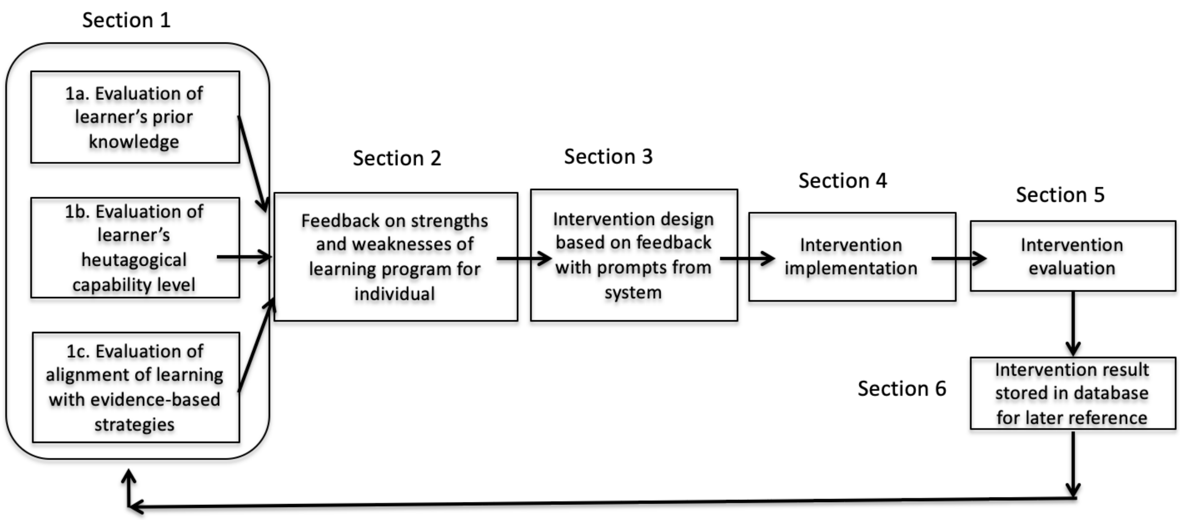


Figure 9.2 Conceptual model of CLEMS as evaluated in Focus Group 2

Notes: This model provides an overview of the DC-NOE-VC process (see Figure 6.6). Sections 1 and 2 represent the DC, Sections 3 and 4 represent the NOE and Section 5 represents the VC. Section 6 represents the database storage and retrieval capability of CLEMS.

In Figure 9.2 Sections 1a, 1b and 1c represent the input functions of CLEMS for capturing information regarding learner prior knowledge; this includes both domain knowledge (prior knowledge) as well as heutagogical levels and the alignment of the learning program or intervention with the CLT model of human cognitive architecture.

Section 2 represents the feedback provided to the teacher which provides an analysis of the strengths and weaknesses of the learning program for the learner.

Section 3 represents the functionality for designing interventions for supporting learners or modifying programs i.e. CLEMS will have a database that teachers can access to identify a range of recommended, evidence-based strategies for strengthening the course content for learners. The strategies will be based on best practices of the application of strategies arising from CLT and pre-loaded into the database in order to facilitate access by teachers.

Section 4 represents the implementation of the intervention within a set time frame based on the varying needs of individual learners to attain schema formation and automation.

Section 5 represents the evaluation of the intervention in terms of learning outcomes. The intervention will be evaluated after the implementation time frame specified in Section 4.

Section 6 represents the functionality of CLEMS to store the results of interventions in the database for tracking of learner progress as well as later reference for data analysis and trend analysis e.g. for identifying common areas of challenge or success for learners.

The completion of Focus Group 2 and the refinement of the conceptual model completed this iteration which then led to the final research iteration, which is detailed in the next chapter.

Chapter 10: Third Data Chapter - Evaluating a prototype of CLEMS

Research Iteration 3 and Focus Group 3

10.1 Introduction

The third and final research iteration of the study commenced after the completion of Focus Group 2. Iteration 3 ran for 14 months until 7 November 2017 on which date Focus Group 3 was conducted to trial the prototype version of CLEMS. The third research iteration took place over an extended time period to allow the development of CLEMS from a theoretical model into a functioning prototype with the support of software developers.

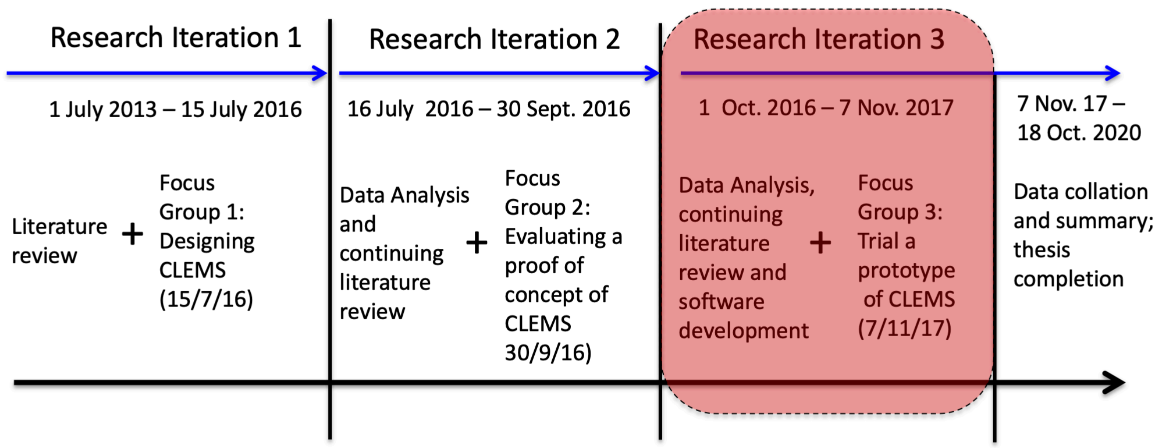


Figure 10.1 Research overview with Research Iteration 3 highlighted

Focus Group 3, in which CLEMS was evaluated, took place in the School of Education on 7 November 2017. This focus group had 11 participants with roles and numbers as follows: Academics (3), Administrator (1), Managers (2), Lecturers (3), Instructional Designer (1) and Student (1). Participants were given a live demonstration of CLEMS, which they evaluated by providing feedback on forms.

The remainder of this chapter outlines the process followed to develop CLEMS as a prototype software application, provides a detailed overview of CLEMS interfaces and functions, and discusses the feedback elicited from this focus group (see Appendix O).

10.2 The software development process

The process of developing the prototype software instrument was initiated with the paid consultation of an expert in spreadsheet applications. The goal of this consultation was to develop CLEMS as far as possible using spreadsheet application formulae, functions and hyperlinks without using costly database capabilities. The cell functionality in the spreadsheet application provided limited prototyping capability, but was valuable in specifying the design details of CLEMS with greater clarity.

The key learning from the spreadsheet consultation process was the necessity to design the architecture of the application to accommodate the requirements of the specification as well as the greatest range of future functions possible. This included improved scalability and user capability, as well as extensibility of CLEMS to support new functional requirements that might arise in future.

After the limited functions of CLEMS were explored using a spreadsheet, a detailed specification of CLEMS was documented (Appendix Q, Figure Q1). A software company in California, USA, was engaged to develop the software application using this specification, with the researcher project managing the development process. The software development company that was engaged to develop the CLEMS prototype used a templated system based on the PHP and MySQL software programming languages, which enabled the development costs to be kept to a minimum.

10.2.1 Software prototype specifications

The following list provides details of the specifications of CLEMS used to guide the software development process. The software was designed to include functionality for:

1. Determining the prior knowledge and capability of learners: the teacher is able to create questionnaires to determine level of prior knowledge of individual learners or to evaluate the level of evidence-based practices incorporated in learning programs.
2. Determining the extent to which courses are evidence-based in terms of compliance with CLT strategies: this function involves the teacher completing a questionnaire regarding the extent to which evidence-based practices arising from CLT research have been incorporated into a particular learning course.
3. Learner completion of a questionnaire to determine level of prior knowledge and heutagogical capability: the learner is able to complete the questionnaire set by the teacher to determine level of prior knowledge in the knowledge domain as well as heutagogical capability.
4. Teacher dashboard view of questionnaire results: the teacher is able to view the results of questionnaires with visual reports on deficits or strengths of learning programs in terms of evidence-based practices, as well as in terms of learner knowledge and heutagogical capabilities.
5. Access by the teacher to a dynamic knowledge database: the teacher is able to drill down to deeper levels of information using hyperlinks to identify strengths or weaknesses of the learning program in terms of the prior knowledge and capabilities of the learner, or in terms of the levels of evidence-based practices (CLT effects and strategies) included in learning programs.

6. Teacher accesses and completes learning intervention design form: the teacher is able to activate a form to design a learning intervention for an individual learner (NOE) or to design an improvement to a course by increasing its compliance with CLT effects.
7. Access to recommender function of CLEMS: the teacher is able to complete the above form (Point 6) using the recommender functionality to inform the choice of strategies and content to strengthen learning interventions within NOEs.
8. Implementation of learning intervention in the form of a NOE: the teacher is able to activate the NOE which expires on the set date and automatically alerts the teacher by electronic notification e.g. dashboard or email (or both), as well as alerting the learner regarding the requirement to validate the effectiveness of the NOE intervention on the set date; the teacher is able to record comments and notes related to the intervention and its outcomes (Naylor, Baik, Asmar & Watty, 2014; Nebel, Schneider, Schledjewski & Rey, 2017)
9. Validation of knowledge by learner, post-intervention: the learner is able to re-take the questionnaire to validate the extent of expertise and heutagogical capability attained through completing the node of expertise by the set date
10. Review: the teacher is able to review the results of the node of expertise intervention using graphical reports provided through a dashboard and provide feedback to the learners
11. Iterative process facilitated: the teacher is able to repeat Points 1–10 (above) with access to the functionality of CLEMS for comparisons of results on an ongoing basis to reflect continuous improvements.

10.2.2 Limitations of the prototype development

The prototype was designed to demonstrate functional specifications of CLEMS and therefore did not have any graphic design features for the aesthetic appearance of the software interface. In addition, the prototype only included sufficient content to verify the functional design of CLEMS.

In addition, a disadvantage of this process was that the database code for the prototype was securely hidden, so future developments would either be limited to the same platform or require complete redevelopment. This limitation, while undesirable in the medium to long term, was a compromise that enabled the prototype development to proceed within the time and budgetary limitations of the study. As noted by Herrington et al. (2007) a potential limitation of using DBR in doctoral studies is the length of time required to engage the process within a community of practice. However, this limitation may be overcome through applying constraints to the scope of projects as was done here.

10.2.3 Final prototype version for testing

The actual development of the prototype occurred from March to October 2017. The final prototype of CLEMS was completed in October 2017 and the date set for its trial within Focus Group 3 was set for 7 November 2017.

10.3 Functional model of CLEMS and screenshots of its user interface

This section provides a detailed functional model of CLEMS as well as screenshots of the user interface as trialled in the third focus group. Figure 10.2 (below) illustrates how CLEMS was a synthesised from the identified theoretical themes and design functionalities into a cohesive system of interrelated functions. These functions are defined from the perspective of personal roles of administrator, teacher, and student.

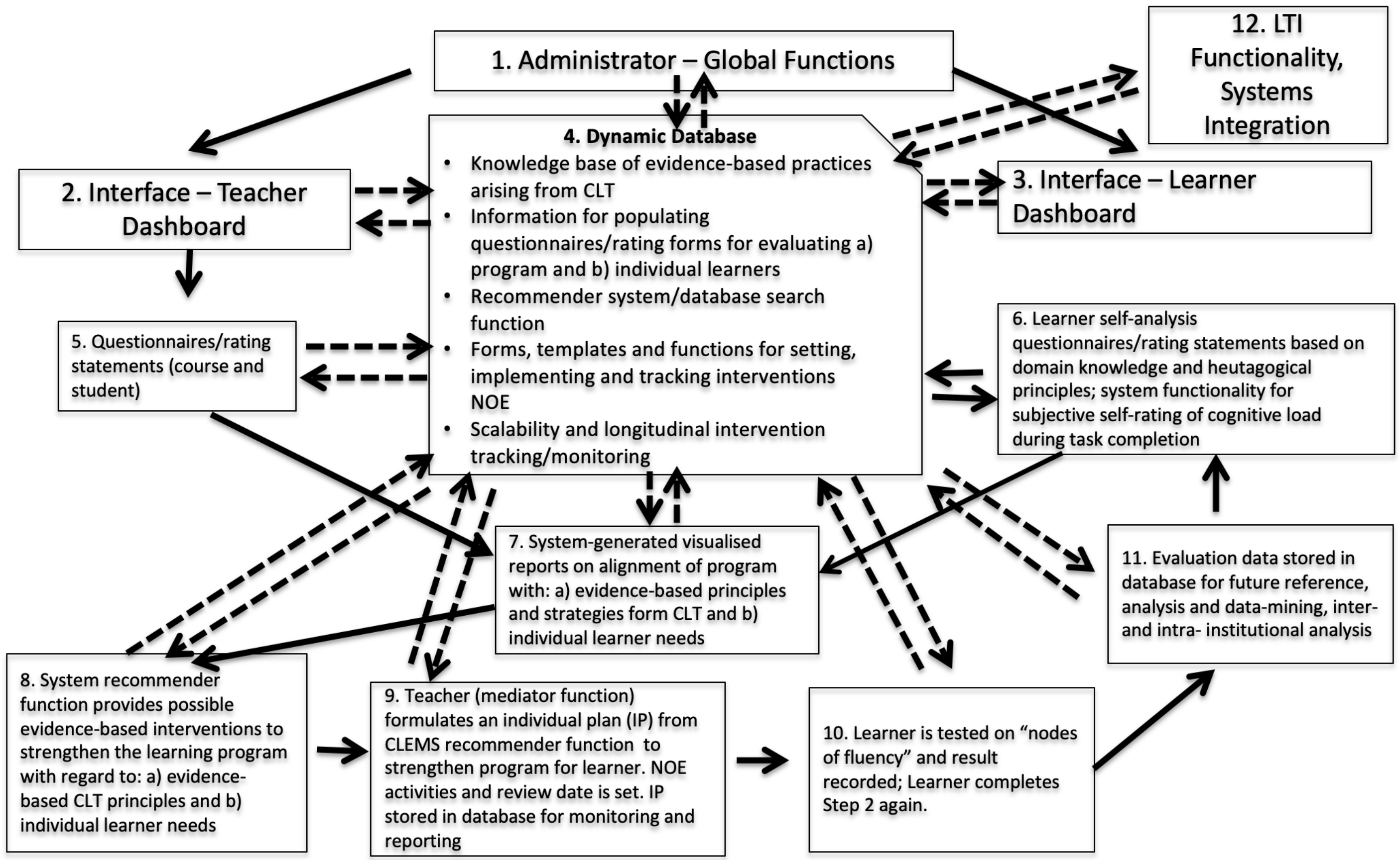


Figure 10.2 Framework for the design of CLEMS

Notes: Figure 10.2 expresses the model that contains a synthesis of the emergent themes of the study to this point in order to arrive at a coherent model for CLEMS. It included functional descriptions of each system component. This set of functions was used to develop the design specification of the CLEMS prototype trialled in Focus Group 3.

Key factors in the development of CLEMS that have emerged to this point include the following characteristics:

a. A systematised framework for managing the design–teaching–learning–evaluation cycle.
b. A mediative–adaptive approach that emphasises the key role of the teacher in adapting teaching interventions to the level of the learner.
c. A personalised approach to the design–teaching–learning–evaluation cycle by taking the learner's prior knowledge and heutagogical capability levels into account in devising new learning interventions.
d. Continuous improvement represents the functional capability of CLEMS to store and provide progressive reports on course improvements and learner progress.

The specific functional parts represented in Figure 10.1 are summarised as follows:

1. **Administrator**: management of global functions e.g. integration of instruments with other systems using Learning Tools Interoperability (LTI) protocols; accessing all interfaces to make changes where required; bug tracking and fixing; working with technical teams for the ongoing development of the system.
2. **Teacher dashboard**: the teacher accesses a dashboard from where key functions can be operated e.g. creating questionnaires, administering cohorts of learners engaged on personalised learning pathways; recording Diagnostic Conversions (DCs), Nodes of Expertise (NOEs) and Validation Conversations (VCs); accessing the Dynamic Knowledge Database (DKD) of knowledge and practice in CLT; creating reports, viewing visualised reports at a detailed level; communicating with individual students and student cohorts.
3. **Learner dashboard**: for accessing progress reports and other information.
4. **Dynamic Knowledge Database (DKD):** for storage of data generated through questionnaires, learning interventions and outcomes, as well as facilitating the access of relevant CLT strategies to teachers.
5. **Questionnaires**: for facilitating course analysis and eliciting information from students regarding prior domain knowledge and heutagogical capability.
6. **Learner self-analysis questionnaire**: for eliciting information from students regarding prior domain knowledge and heutagogical capability.
7. **Visualised report generator**: a protected-access dashboard for use by teachers and other stakeholders for viewing data related to the continuous improvement of courses and learner progress.
8. **"System recommender":** a part of the DKD that provides recommendations to teachers for strengthening learning interventions in programs and courses, as well as for individual learners.
9. **Intervention plan form**: for designing and setting parameters for the delivery of NOEs
10. **Learner evaluation**: post-NOE evaluation to determine the impact of the NOE intervention.

11. **Storage**: evaluation data storage capability in DKD for ongoing learner monitoring and analytics.

Points 1–11 from Figure 10.1 are elaborated in the following sections where the interactions between components and their resultant effects are explained.

Part 1: Administrator

The Administrator has root-level or super-user status in order to perform high level functions such as adding teachers and courses to the system, as well as assigning teachers to courses. In future iterations of CLEMS beyond the current goal of prototype development, some of these high level functions may be facilitated through LTI (Learning Tools Interoperability) capabilities e.g. integration of the system with a student management system (SMS).

Part 2: Teacher interface

Teachers have access to the system via a visualised dashboard after logging in to a password-protected personal learning environment. The dashboard will have functionalities to:

a. create questionnaires that evaluate courses against a CLT-derived standard of learning design quality.
b. create evaluation forms for students to determine their prior knowledge and heutagogical capability levels, and to email these forms to students.
c. access the DKD of evidence-based practices based on CLT effects for designing NOEs and for informing practice.
d. set up intervention plans based on NOEs that will be implemented in appropriate time frames according to the needs of individual learners.
e. view visualised reports generated after the NOE intervention has run based on stored data that provides a visualised report of the strengths and weaknesses of courses based on compliance with CLT principles, effects and strategies.

Part 3: Learner interface

Learners access the system via a visualised dashboard after logging in to a password-protected personal learning environment. Learners are able to view visualised reports that reflect their knowledge and capability profile as well as the NOE which they have completed or in which they are currently engaged.

Part 4: Dynamic Knowledge Database (DKD)

The database represents the core of the system, containing the following features and functions:

a. a knowledge base of evidence-based practices arising from CLT with the capability of being updated on an ongoing basis with new research and effects for strengthening learning
b. evaluation questionnaires/statements for evaluating programs (courses), learners or both
c. a recommender system that teachers can access and search for the most appropriate strategies to use to strengthen learning programs or to design NOEs. The recommender functionality may be based on teachers engaging search functions, or in later iterations of CLEMS, via programmed algorithms that suggest possible evidence-based interventions to teachers based on their input regarding courses, programs or individual learners
d. forms for writing NOEs which are targeted interventions that support learners through specific learning barriers to the point of schema automation
e. technical features of scalability, data-sharing and visualised data reports.

Part 5: Questionnaires/rating forms: course analysis and learner

The questionnaire/rating statement "engine" of the system allows the teacher to create questionnaires to evaluate the course against the CLT-derived, evidence-based standard and the learner's prior knowledge and heutagogical capability levels.

These questionnaires will have been previously set up by the teacher using pre-populated questions/rating statements that have been stored in the system database. Questionnaires/rating forms have the functionality to be emailed to students to complete with learner responses recorded in the DKD.

Part 6: Learner self-analysis questionnaire/rating statement form

The learner self-analysis questionnaire is designed to evaluate the learner's prior knowledge of the subject domain and heutagogical capability. The learner's profile is generated in a comparative report against the program/course evaluation report, visually demonstrating the strengths or weaknesses of the course against the learner's knowledge and capabilities.

The learner's self-analysis forms part of the personalisation and individualisation processes within the system.

Part 7: Visualised reports

A key function of CLEMS is to generate visualised reports for both teachers and individual learners. Comparative reports that show the strengths and weaknesses of the program in terms of the learner's prior knowledge and capabilities enable the teacher to make more informed decisions about structuring criterion-referenced interventions (NOEs) based on CLT effects.

Part 8: Intervention recommender

The intervention recommender functionality of the system is an active part of the system designed to inform teachers of evidence-based practices to strengthen their courses. For example, a questionnaire may reveal that a course is weak in supporting learners in developing the evidence-based skill of self-explanations (Sweller, Ayres, Kalyuga, 2011, p. 188). In this case, the system would recommend an increase of this skill and provide examples of how this skill may be incorporated into the course.

Following this recommendation, the teacher would write this skill as a NOE into an intervention plan using a form within the system. The NOE would be implemented with a start and end date. After the end date of the implementation plan, the learner would redo the questionnaire to provide evidence of the result of the intervention. This would require the learner to demonstrate a well-developed schema which has been automated to a degree that enables the process of problem solving or other tasks prescribed within the NOE.

Examples of automated NOEs demonstrated by learners may be reading at a certain level, multiplying double-digit numbers, solving chemical equations of a certain type, or learning to create an HTML web page. Based on visualised feedback, the teacher would then be able to create a new intervention implementation for the learner. The new intervention may focus on the same strategy if necessary or the teacher may implement a NOE based on a new learning effect.

In alignment with the "narrow limits of change" principle, the system operates on the principle that only one node of expertise should be administered at a time. This is to align the intervention with the functional limitations of cognitive architecture, as well as to provide a more accurate relationship of causality from the intervention and the results of its implementation. Moreover, research evidence strongly suggests that the acquisition of expertise, or schema automation requires deliberate, accurate practice over extended time periods (Ericsson, Krampe & Tesch-Romer, 1993).

Effectively, the iterative process of implementing NOEs transforms the course as well as the learner's knowledge and capability profiles a single factor at a time as a CI process. This incremental approach to change is also referred to as a kaizen approach to CI (Khayum, 2017; Suarez-Barraza & Rodriguez-Gonzalez, 2015).

Part 9: Intervention plan generator

The intervention plan generator provides a form for teachers to create NOEs and set start and finish dates for their implementation. The intervention plan generator has the capability of a compulsory requirement for teachers to engage in consultation with another teacher when planning the intervention. The intervention plan (NOE) encourages a reflective and collaborative process for the teacher that also has an educative facet as teachers become more familiar with the purpose and use of CLT strategies.

Part 10: Learner and teacher evaluation: post-intervention

After the NOE has been implemented in the specified time frame, the teacher and learner complete the original questionnaires again to evaluate the impact of the NOE.

NOEs may be repeated at the teacher's discretion and successive iterations of interventions are stored in the database and may be compared over extended time periods through visualised reports. For example, the incremental changes to the course may be evaluated over periods that extend beyond the current academic year. In addition, the incremental changes to the learner's domain knowledge and heutagogical capability may also be tracked and compared over a number of years through visualised reports. This long-term process represents the "inside-out" aspect of the LASO model (Uys, 2015) where organisational transformation occurs through adjustments to key parameters at a system level. Specifically, long-term transformation of learning through small, controlled, incremental changes permits an alternative approach from learning environments where learners are pressured to achieve outcomes that may be based on poorly formed, erroneously formed or unautomated schemas, instead of intellectual advancement in knowledge in specific domains through accurate schema development and automation.

This process represents the enactment of a criterion-referenced process where knowledge and capability acquisition are not compressed into artificial, short, time structures, but are extended according to evidence-based processes of expert skill acquisition.

Part 11: Intervention iteration data stored in database

The database represents the knowledge base of the system, where pre-populated information as well as generated data are stored. The use of the database facilitates a long-term approach to individualised and personalised learning. As noted in the previous section, a learner's profile may be reviewed or evaluated over longer time spans than the current academic year.

Within institutions, NOEs within specific knowledge domains may be added to the database for other teachers to share: class analyses may be compared and students may be supported through the strengthening of specific domain and heutagogical skills based on NOEs that teachers have stored in the system. Future iterations of CLEMS beyond this study may include data-mining across institutions and between institutions (subject to privacy laws and data-sharing policies), thus serving as a mechanism for sharing knowledge for the long term benefit of learners. In this way, CLEMS could mitigate the problem where, “Many university processes fail to benefit from the insights and recommendations of the employees who are intimately involved in the process but have no formal mechanism to share their concerns and suggestions" (Balzer, Francis, Krehbiel & Shea, 2016, p. 7).

CLEMS has an internal standard of learning design derived from CLT in its database. This may be termed the first layer of evaluation. CLEMS also has the functionality to monitor interventions during in situ learning environments, thus facilitating the second layer of evidence-based practice i.e. while the implemented strategies are derived from evidence-based effects arising from CLT, each one is subjected to an additional layer of testing as it is implemented within in situ learning environments through cyclical iterations.

In summary, the model (Figure 10.2) represents CLEMS as a synthesis of the various features and functions arising from the literature review.

10.4 CLEMS interface and functions: Screenshots and descriptions

The following figures (10.3 to 10.3.17) provide a graphic representation of the interfaces of CLEMS with the functions demonstrated to participants in Focus Group 3 of this study. Some content has been modified to simplify the demonstration process but all the functionality of CLEMS is represented and addresses the research question regarding how CLT can inform the design of CLEMS. The circled number references are explained in the notes beneath each figure using corresponding numbers in parentheses:

e.g. 1 is referenced as (1) in the notes, etc.

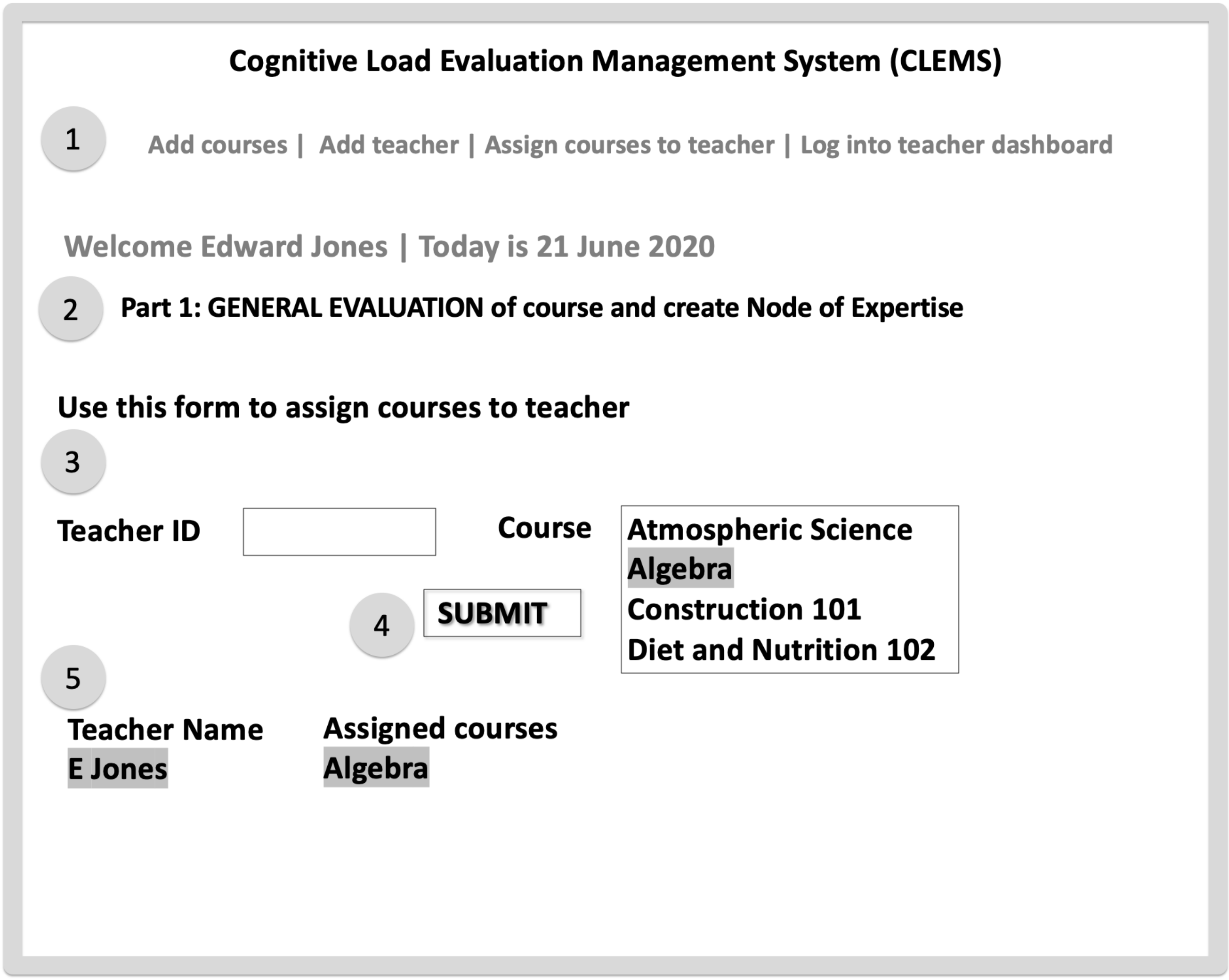


Figure 10.3 This figure shows the Administrative functions for assigning courses to teachers

Notes: The functions are: (1) Navigation menu: add courses to the system, add teachers to the system assign courses to teachers, log into teacher dashboard (2) Function: General Evaluation and create NOEs (3) Enter teacher ID (6).

Select course from drop down menu (4) Click submit (5) View of course assigned to teacher in CLEMS. This figure shows that Algebra has been assigned to the teacher E Jones.

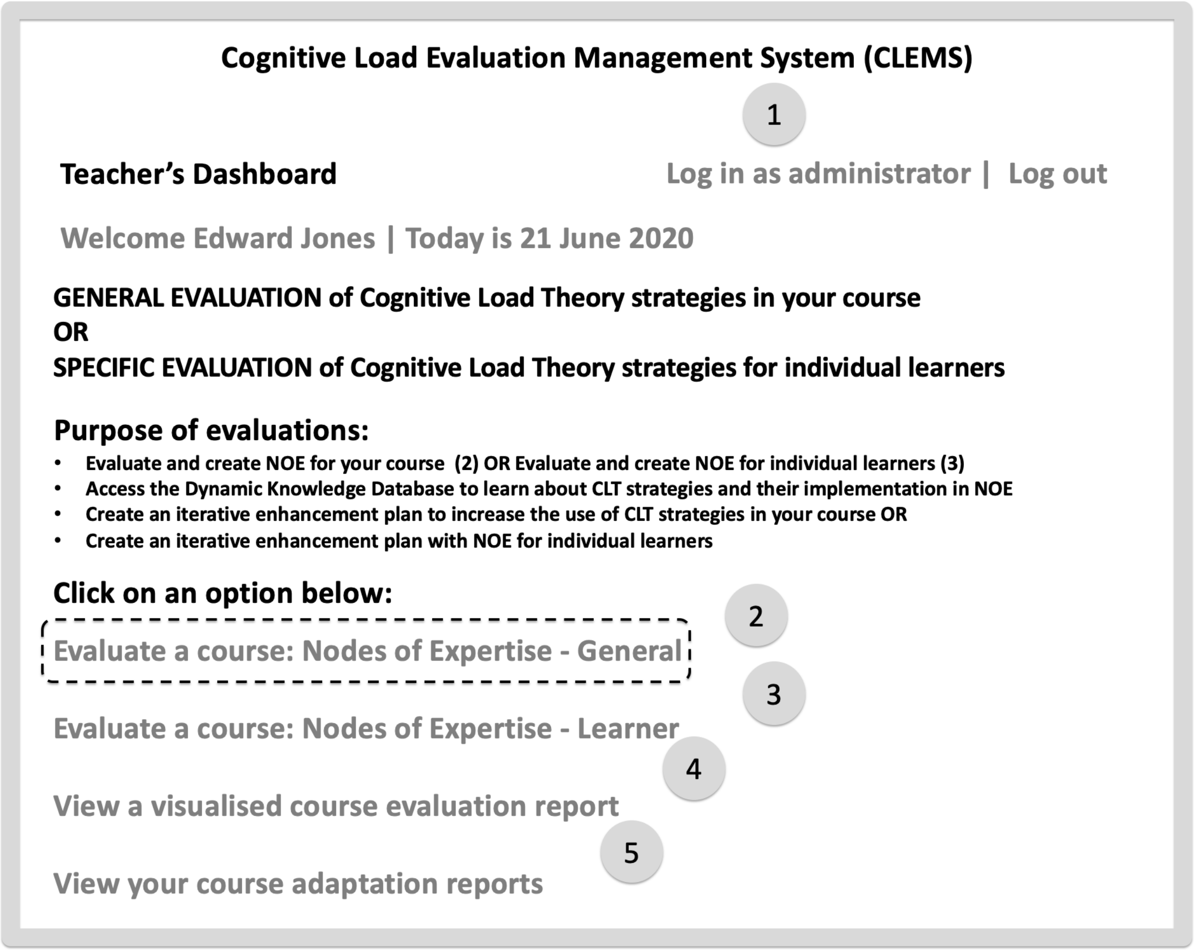


Figure 10.4 This figure shows that the Teacher's Dashboard

Notes: Edward Jones has logged into CLEMS. On this page teachers can select the option evaluate and increase the use of CLT strategies in a course or to evaluate the suitability of a course for individual learners in terms of its inclusion of CLT strategies.

Improvements to the course are expressed in the form of a Node of Expertise (NOE) created by the teacher that includes specific domain knowledge (e.g. a domain-specific concept, procedure or principle) and is presented in the format specified for a CLT strategy (e.g. worked example, goal-free problem, self-explanation strategy, etc.).

In this example, the teacher selects the link to evaluate the use of CLT strategies in a course (dotted shape represents selected link) (2). This link opens Part 2 of CLEMS as shown in Figure 10.5 (next page).

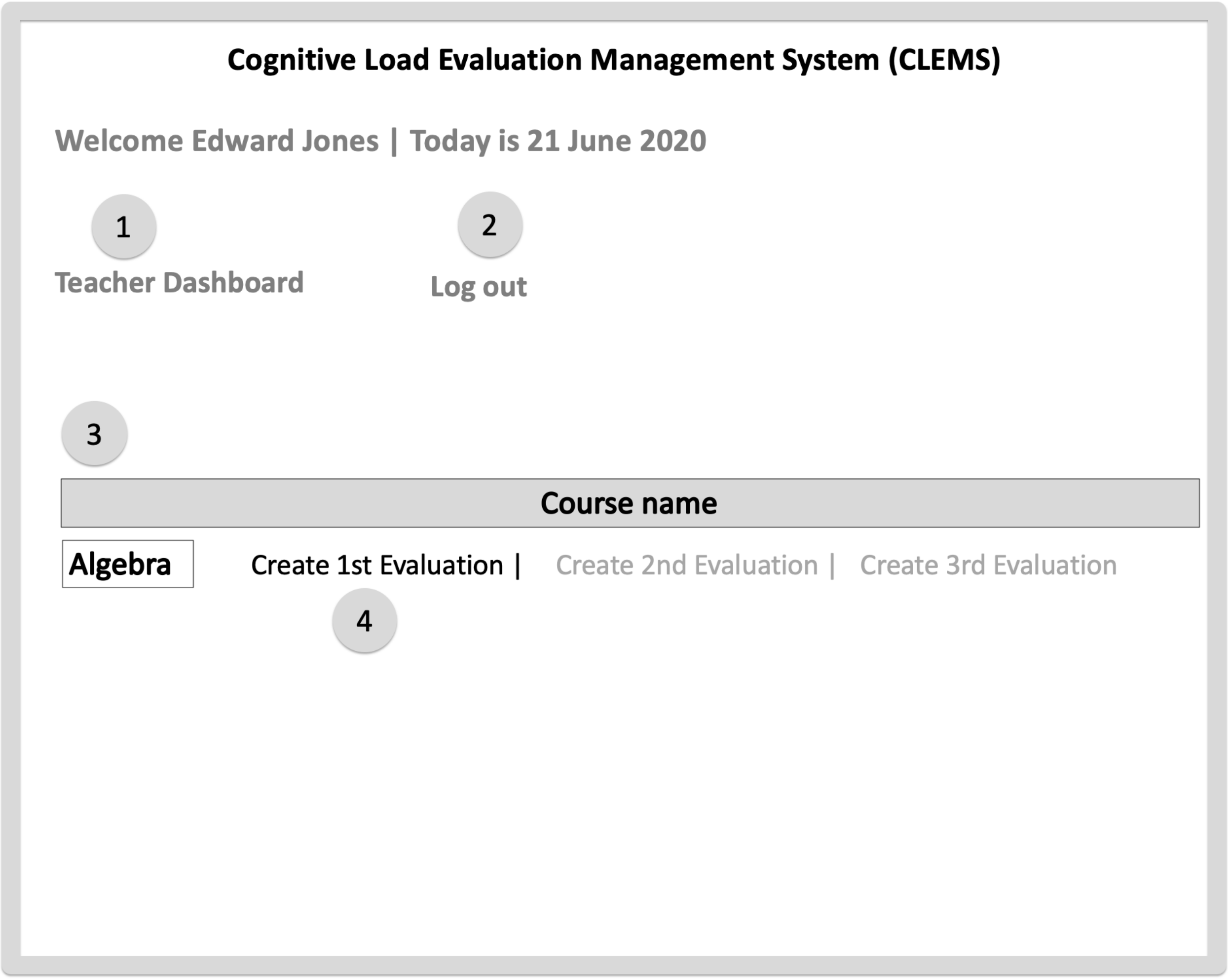


Figure 10.5 On this page the teacher has the option of creating evaluations

Notes: In this example an evaluation or for the Algebra course will be selected.. The following functions are provided: (1) teacher dashboard (2) log out link (3) name of course being evaluated (Algebra) (4) active link shown for creating first three course evaluations.

Links to second and third iterative evaluation are not accessible until the first evaluation has been completed. CLEMS has the capability of creating unlimited iterative evaluations but the prototype only has the option of three evaluations.

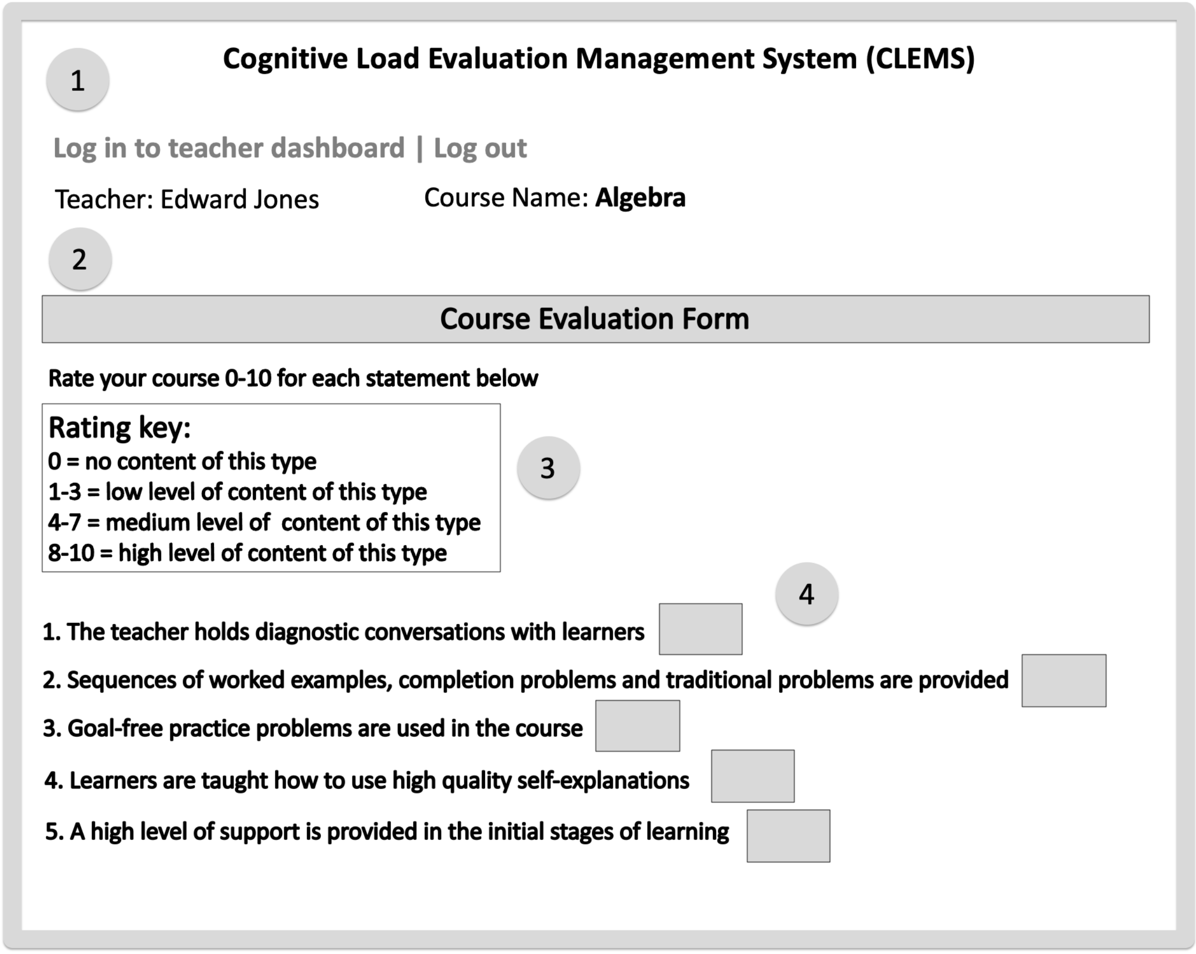


Figure 10.6 (1)This page contains the course evaluation statements

Notes: Five sample statements are provided in list numbered 1–5) (2) course evaluation form header (3) instructions and evaluation rating key (4) sample evaluation questions to identify the extent to which specific CLT strategies are used in the course, with blank spaces for teachers to enter rating scores. Diagnostic conversations (DC) (Statement 1) support the teacher in identifying levels of prior knowledge and heutagogical capability of the learner (see Section 10.4).

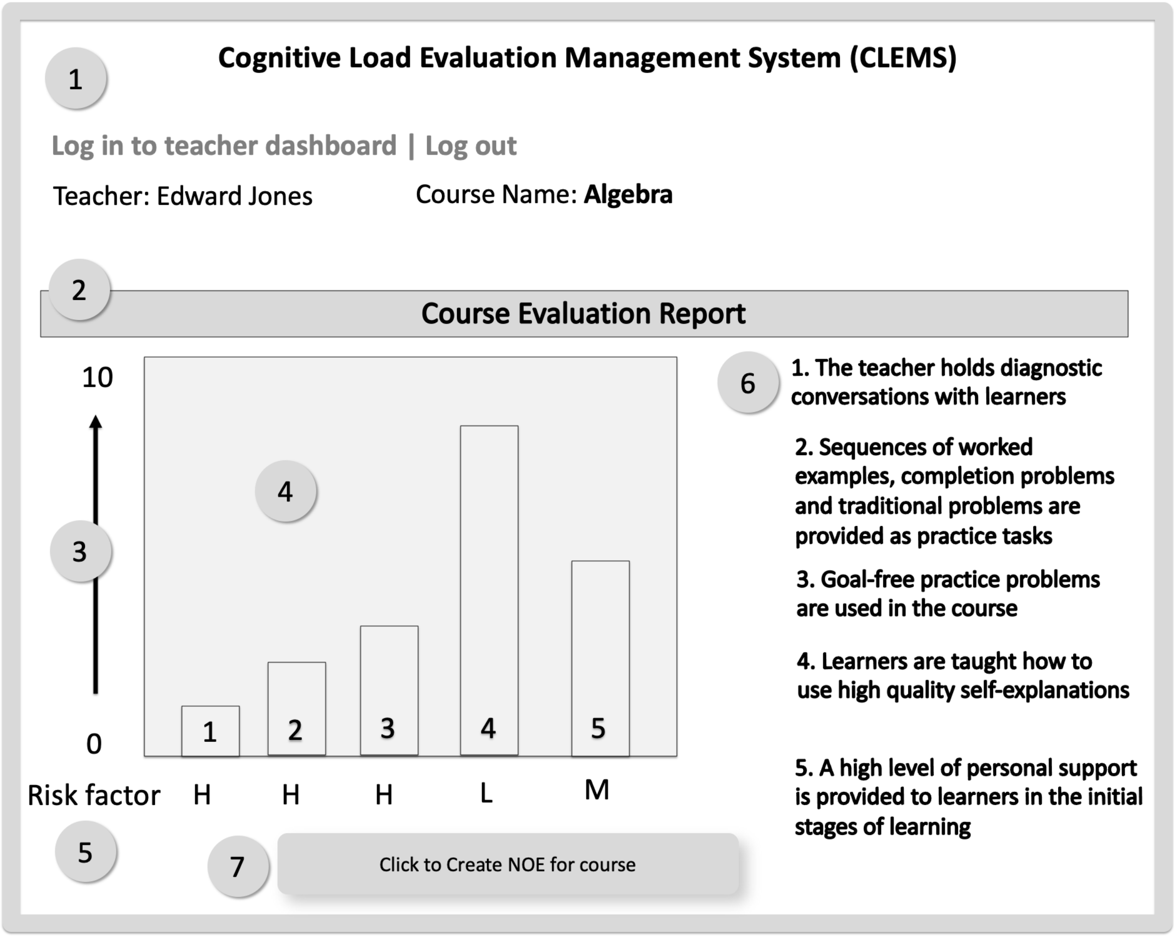


Figure 10.7 Visualised report (1) with teacher and course name identified

Notes: (2) shows a bar graph with the teacher's rating levels for each evaluation parameter as completed in Figure 10.3.5 (4) shows the bar graph providing feedback from the course evaluation form rated on a scale of 1–10 (3).

(5) the risk level associated with each parameter is shown beneath the bar graph e.g. Q2 (Parameter 2) which has a rating of 2/10 assigns this as high risk to learners due to low level of inclusion of this evidence-based parameter; risk also implies that learners may learn by rote and not understand the governing rule or principle of a problem-solving step i.e. at risk of not understanding why they are doing a particular action or step of a task. On the right (6), each parameter that has been rated is shown and teachers can toggle each parameter on or off.

For example in this figure only five parameters are shown but teachers can activate as few or many as required e.g. a teacher may choose to view parameters with ratings below a certain score. Teachers can click on each parameter (each bar of the bar graph) to access the DKD to learn about the particular underpinning CLT effect and how to apply it, with examples provided – this represents the recommender function of CLEMS.

Beneath the graph is a button (7) for teachers to create NOEs for the course i.e. to open a form for setting up a NOE to increase the use of the CLT strategy underpinning one of the parameters. Single parameter modifications to courses are encouraged in order to measure the impact of changes over time without confusion regarding which variable resulted in the change.

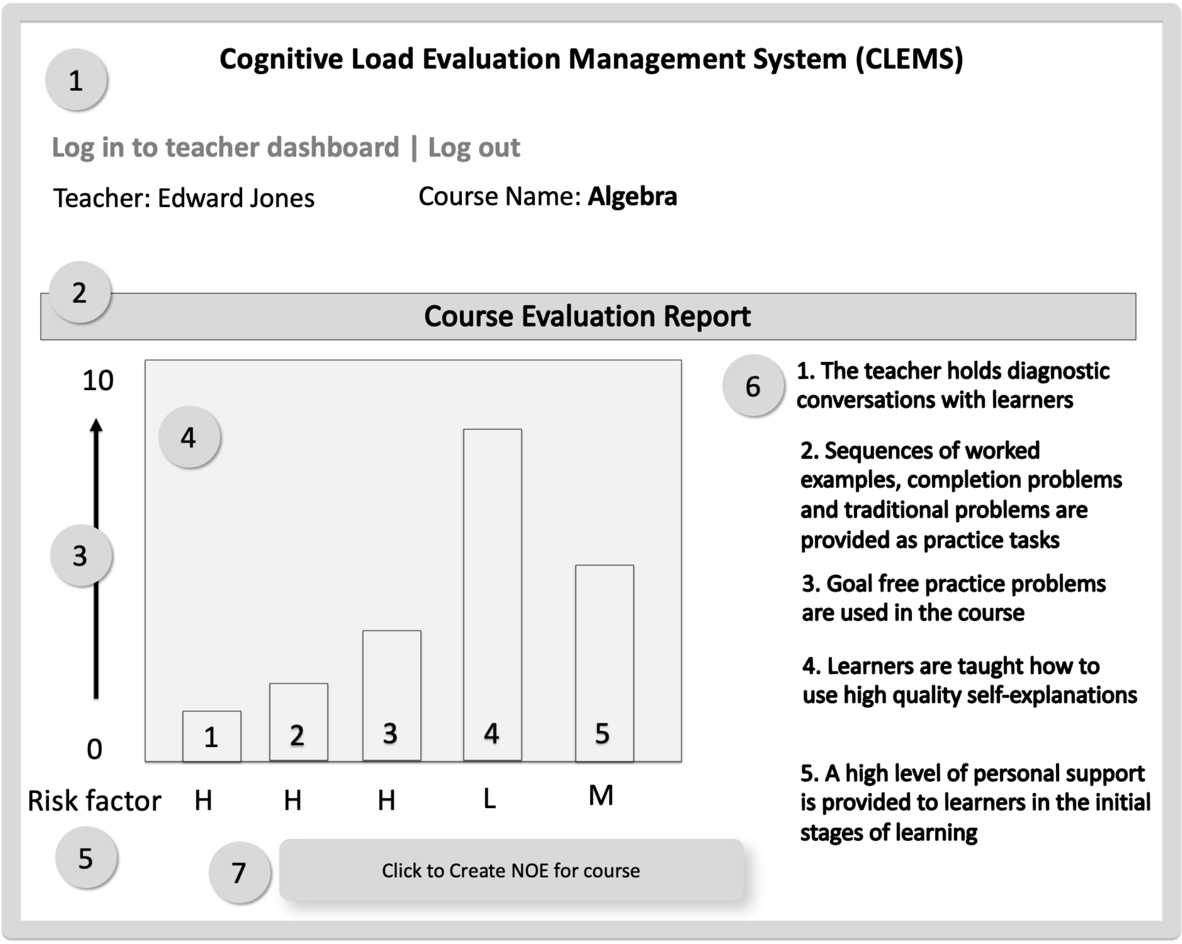


Figure 10.8 Visualised report (1) with teacher able to access the Dynamic Knowledge Database

This information is used to develop a NOE intervention, as illustrated in Figure 10.10 to strengthen the pedagogy of the course by increasing the inclusion of specific CLT strategies. Figure 10.9 reflects the DKD recommender function that provides teachers with specific processes, procedures, principles and examples for implementing the CLT effect in their own teaching context.

Cognitive Load Evaluation Management System (CLEMS)
Dynamic Knowledge Database Entry

Worked Example Effect

Background: The worked example effect is the best known and most widely studied of the cognitive load effect. The worked example effect throws light on the very foundations of human cognition (Sweller, 2006, p. 1). This effect is used to reduce cognitive load for novices engaged in complex learning.

Explanation: Worked examples provide learners with explanations of every step of a problem as it is solved. This strategy is often used in a 3 step process, with faded guidance in completion problems (some steps are explained and some steps left for the learner to complete). After studying worked examples and doing completion tasks, learners then progress to doing traditional problems by doing every step of practice problems. The process targets the building of specific schemas that will form the prior knowledge base of learners when they engage in solving this type of problem task.

The sequence of worked examples, completion problems and traditional problems can be used as a combined strategy to lead learners to mastery of particular problem types. Worked examples help learners to solve problems by applying rules principles and understanding rather than by rote memory.

How to apply this strategy: Select four practice examples with similar surface features. The aim is to guide learners to think about each step and internalise its governing rule or principles and apply it to further problems.

Part 1: Worked example

a. Break the first problem down into steps to show the process of solving it
b. Provide explanations for each step with additional supporting information about the underlying principles or rules governing the problem resolution i.e. explain both "how" and "why" for each step
c. Indicate how experts think about this type of problem and use analogies to ensure learners have the correct mental representation of the problem type.

Part 2: Completion problem with faded guidance

a. Break the next problem down into steps to show the process of solving it, as per Part 1.
b. Decide how many steps will be explained to the learner and how many the steps the learner will do unaided. For example in a 5 step problem with explained steps (E) and learner completed steps (L), possible sequences could be: EEEEL, EEELL, EELLL or ELELL.

Part 3: Traditional problem with learner completing every step

Let the learner complete every step of the problem. A worked solution of every step may be provided for reference after the problem has been completed.

Figure 10.9 Example of a DKD entry with information on the worked example effect

Notes: The DKD is accessed by rolling a mouse cursor over bar graph or list of statements. An example of an entry in the DKD for this statement is provided in Figure 10.9. This information supports the teacher in designing NOE interventions for modifying the course through the NOE form (7).
This information is used to develop a NOE intervention, as illustrated in Figure 10.10 to strengthen the pedagogy of the course by increasing the inclusion of specific CLT strategies. This figure (10.9)

reflects the DKD recommender function that provides teachers with specific processes, procedures, principles and examples for implementing the CLT effect in their own teaching context

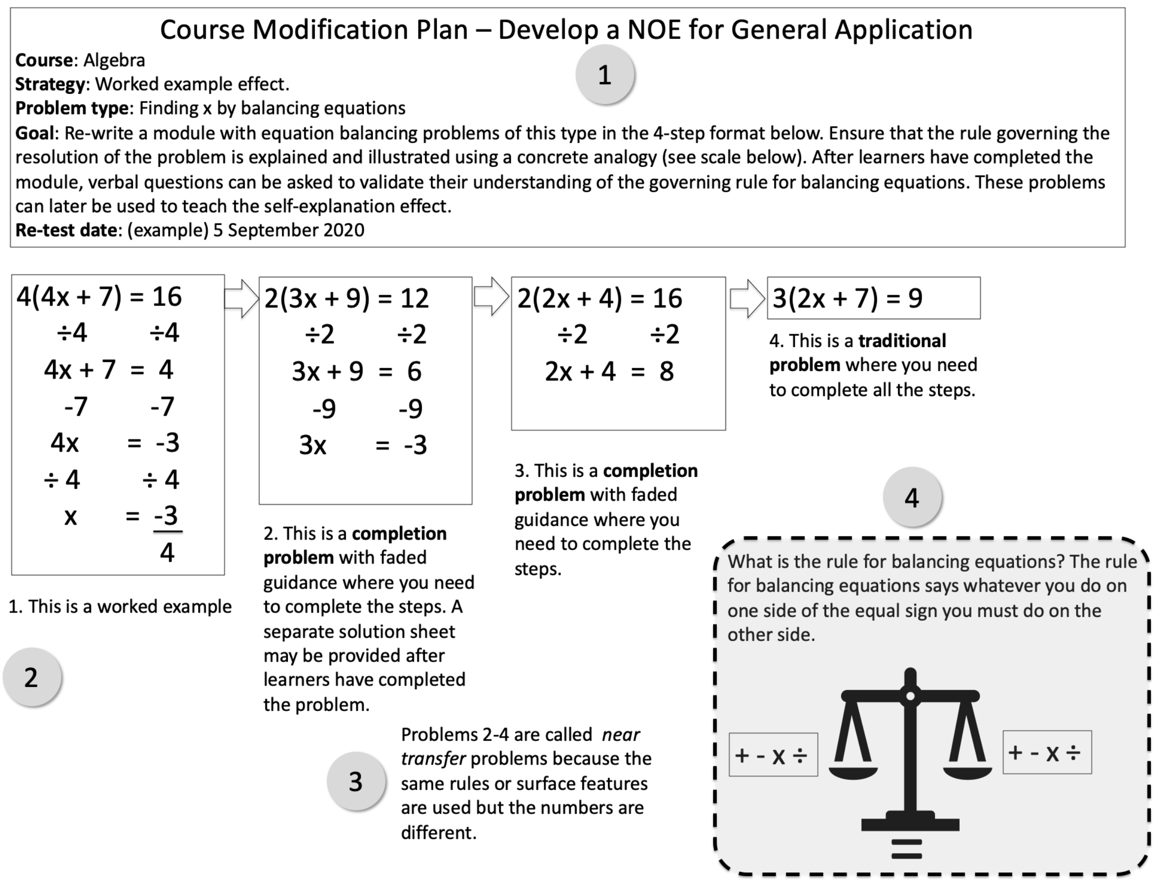


Figure 10.10 Example of a NOE intervention plan

Notes: Figure 10.10 (1) demonstrates the use of a NOE intervention plan with the example of solving for x in the equation 4(4x + 7) = 16 as shown in (2).
The NOE intervention plan form is activated in CLEMS by clicking the Create NOE button (see Figure 10.8, point 7). This opens the form for the teacher to design the course modification NOEs. Links to resources may be added to this page or to externally hosted examples. The 4 examples contain additional explicit explanations (3) and (4) on the governing principle of the problem in order to foster the learner's transfer of the principles to other similar problems.

The worked example effect is closely related to the self-explanation effect, where learners articulate to themselves the procedural steps as well as the conceptual inferences on which the steps are based. The expertise model of learning posited by CLT includes recognition of the type of problem being solved (equation balancing) and the rule governing the resolution of problems (same operations on each side of the equation).

Using an expertise model ensures that learners know how and why a problem solving step is being performed, with additional information showing how an expert would solve the problem. Additionally, using a concrete analogy e.g. of the scales in this example may support some learners in forming of the correct mental representation of the problem and avoidance of rote memorisation of procedures.

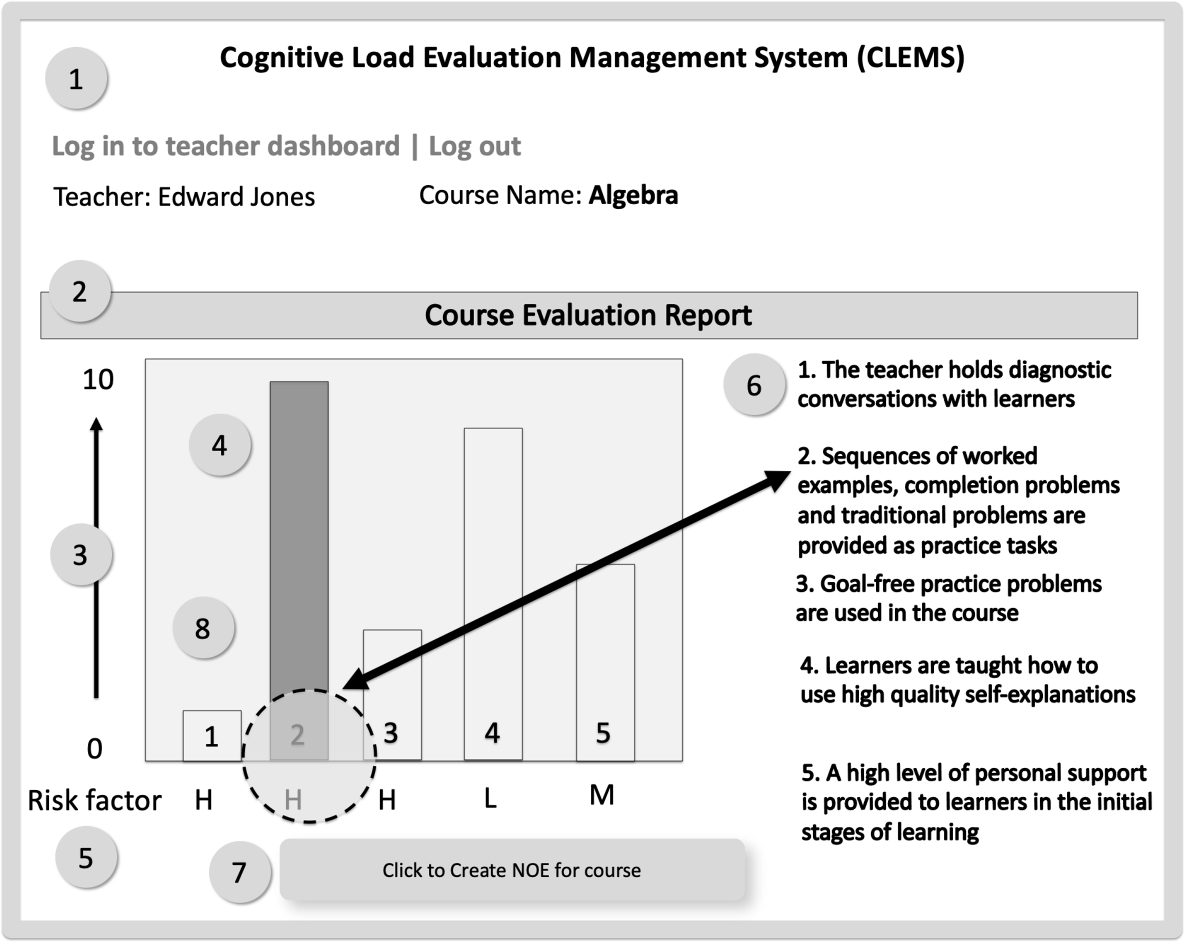


Figure 10.11 A re-evaluation of the course (see Figure 10.6) by the teacher

Notes: This re-evaluation example in the bar graph shows the outcome of including worked examples in the course. Depending on the performance of learners from the intervention, further interventions can be created using the same parameter or a different parameter e.g. goal-free practice problems (parameter 3) can be developed for the course.

By modifying the course through the inclusion of single, specific strategies and then reviewing the performance of learners on tests, links can be made between learning design and learning outcomes i.e. it is not assumed that any intervention will result in change, but CLEMS facilitates the testing of every implementation to determine the level of impact on learners for that particular intervention.

For example, if learners show a strongly positive increase in performance in this type of problem solving example after the first intervention, an alternative parameter may be used to create interventions to strengthen the course further. Alternatively, if the intervention shows no significant improvement in learner performance, then an alternative strategy may be used to create an intervention.

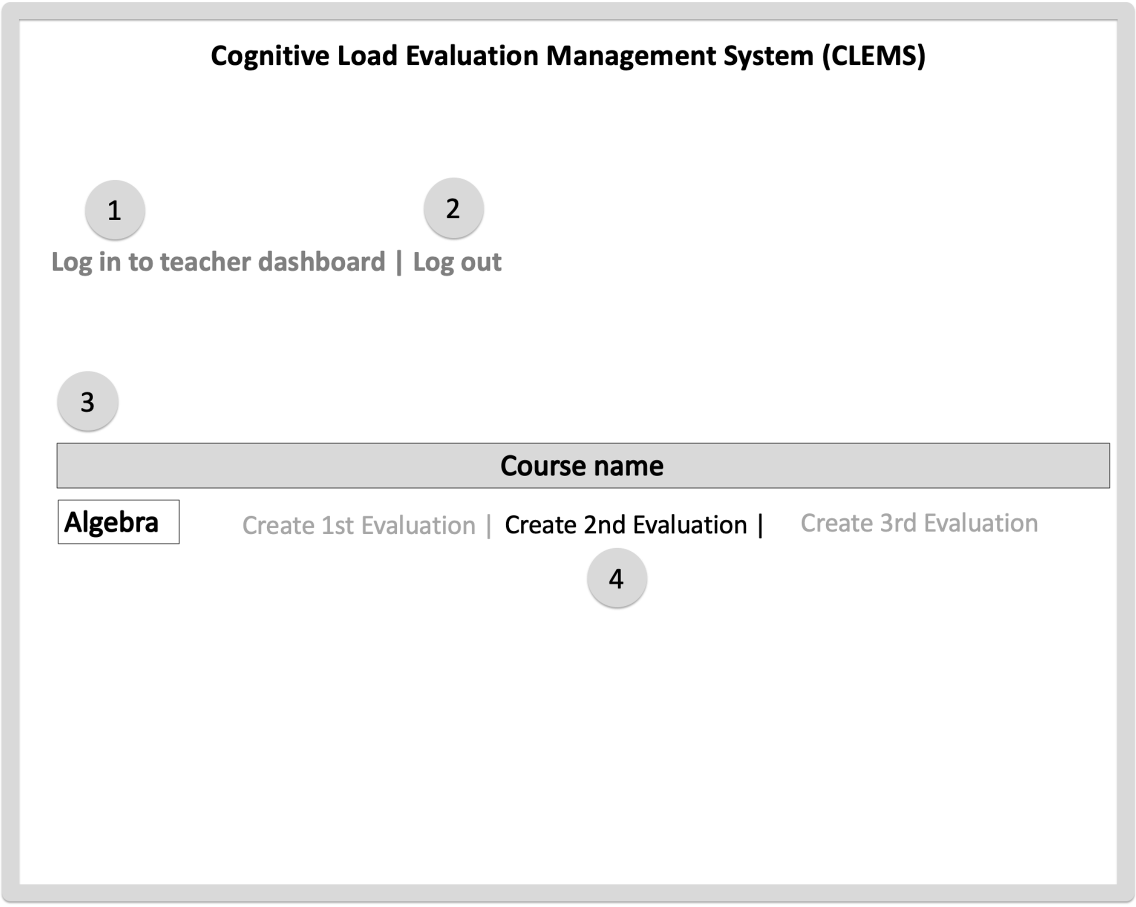


Figure 10.12 Initiating subsequent evaluations (4)

Notes: After the first evaluation has been designed and implemented, teachers may return to the Teacher's Dashboard and conduct additional evaluations. In this figure (4) shows the currently active 2nd evaluation option, with first and third evaluations being inactive and greyed out.

As noted in Figure 10.4, further evaluations may include the same or different parameters. This intervention represents a NOE for an entire class or cohort. All of the NOEs and other information recorded in the system may be accessed for future reference and use e.g. data mining or the re-use of NOEs in the development of other courses.

The same process may be followed for designing a NOE for an individual learner as demonstrated in Figures 10.13–10.15.

10.5 Structuring Nodes of Expertise

In the previous section, Figures 10.3.1–10.3.11 demonstrated the process of developing NOEs for increasing the use of CLT strategies in courses. In this section, figures 10.4.1–10.4.10 illustrate the use of CLEMS for designing and implementing NOE interventions for individual learners.

Stage 1: A Diagnostic Conversation (DC) is scheduled for the teacher to discuss progress with a learner. The DC is based on responses the learner provides to an initial questionnaire about knowledge and capability levels in a specific domain (e.g. algebra), where the teacher identifies specific barriers to learning. The teacher uses diagnostic tools to support the DC process. These diagnostic tools include the proposed Knowledge/Heutagogy Quadrant (see Section 10.15) and the Expertise Pathway (see Section 10.16) as part of the DC to target areas of difficulty for the learner as specifically as possible. These areas of difficulty have been variously defined in the literature as troublesome knowledge, threshold concepts, barriers, blockages or impediments to progress. All areas of difficulty represent hindrances to the learner's progress towards the next stage of expertise in a specific knowledge domain.

Some examples to barriers that a teacher may identify for developing a NOE may include insufficient knowledge of the following: Pythagoras's theorem (geometry); balancing chemical equations (chemistry); the difference between meiosis and mitosis (molecular biology); the difference between mass and weight (physics); which physics formula to use for which type of problem; irrational numbers (mathematics) e.g. the square root of -1.
After identifying the specific area of difficulty that a learner is encountering, teachers also question the learner about their mental representations of the type of problem in order to identify the level and quality of the learner's schema development. The learner's schemas for the type of problem may be at one of seven levels:

a. unformed (no knowledge of the subject).
b. poorly formed (incomplete knowledge; the learner has not internalised or automated the concept).
c. erroneously formed (learner is using an erroneous mental representation or may have an einstellung i.e. fixed mindset.
d. formed but not automated (the learner understands the parts of the problem but these parts have not yet been integrated or automated for immediate application).
e. formed and automated for near transfer (problems with similar solution steps but different surface features e.g. triple-digit multiplication with different numbers.
f. formed and automated for far transfer (problems with some different solution steps and different surface features).
g. automated for authentic application in complex contexts with fluidity of thinking and a high level of situation awareness i.e. the expert application of problem solutions.

In the DC, the teacher may identify that current work assigned to the learner may be at an inappropriate level as determined on the following scale:

1. Pre-novice
2. Novice
3. Advanced beginner
4. Competent
5. Proficient
6. Mastery
7. Expert.

For example, a learner may have prior knowledge at a novice level but is floundering due to set tasks being at a much higher level e.g. Competent (Level 4). Alternatively, a learner who is already proficient in the domain tasks may have been assigned tasks at a lower level e.g. Novice, resulting in the expertise reversal effect occurring where the learner does not advance, or may even regress in progress.

Stage 2: After the DC has been conducted, a NOE is created by the teacher. This is the design and implementation of a domain-specific intervention with various examples that incorporate a CLT strategy. In addition, NOEs provide the learner with supplementary information about identifying problem types and the rules governing their resolution, as well as how experts think about the type of problem and concrete analogies for representing the problem. The aim of the NOE is to ensure that the learner automates the domain-specific knowledge through in-depth explanations, scaffolded steps and deliberate practice.

Stage 3: After the NOE has been implemented, a Validation Conversation (VC) is scheduled in which the learner's performance is discussed to determine the impact of the intervention. The aim of the VC is to ensure that the learner has automated the domain-specific schema presented in the NOE so that future problems based on the NOE concept are not solved by the default means–ends analysis process but in a forward-working, schema-based process.

Notes:

- Due to the time required to develop NOEs, it is recommended that teachers collaborate to develop NOEs, which can be stored and shared for re-use
- The impact of the intervention can be recorded in CLEMS and used for future reference to the learner's progress or to refine and redevelop curriculum materials
- Teachers can record problems or challenges associated with implementing the NOE
- Learners can provide feedback on the experience of the intervention.

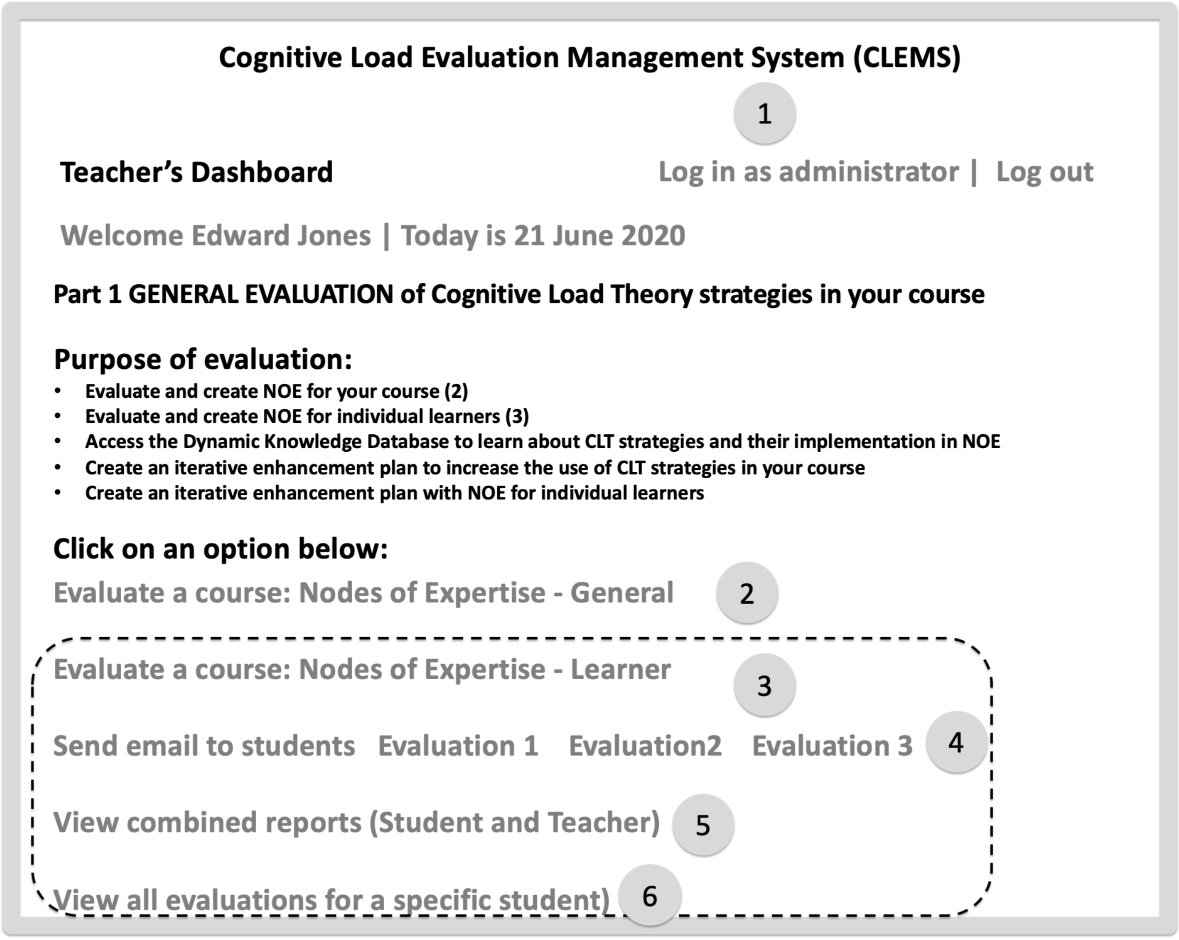


Figure 10.13 Options for functional selections on the Teacher's Dashboard

Notes: This figure shows the page where teachers can select the option to evaluate and increase the use of CLT strategies in a course or to evaluate the suitability of a course for individual learners. In this example, the options related to evaluating an individual learner are shown (3), (4), (5) and (6).
The teacher always evaluates the course (2) as a first step. This is because the feedback provided by the learner from the email questionnaire (4) sent to learners will be compared with the teacher's evaluation of the course (5). The following sections illustrate the functions of (3), (4), (5) and (6).

CLEMS
Email link to Learners: Self Evaluation Questionnaire

Dear Student

Please click the link below to complete the first self-evaluation questionnaire for Algebra.

Thank you,
Mr Jones (algebra teacher)

Questionnaire

Please answer on a scale of 1-10 where 1 is low and 10 is high.

1. I have the opportunity to discuss my progress in this subject with my teacher.
2. I know how to study using worked examples, completion problems and whole problems (every step) on my own.
3. I know how to solve problems using a goal-free strategy.
4. I know how to use high quality self-explanations to strengthen my learning ability.
5. I have access to expert support when I need it during problem-solving tasks.
6. I know how to schedule study time to complete my learning tasks.
7. I believe that I have the ability to master the problems I am required to solve.
8. I know how to represent knowledge with pictures and diagrams to understand it better.

Figure 10.14 Email form for learners to conduct self-evalautions

Notes: This figure shows a sample Evaluation 1 questionnaire sent to learners via email (1), which asks the learner to respond to self-reflective questions about their domain knowledge (statements 1–5) and heutagogical capability (statements 5–8).

Responses to this questionnaire provide information to the teacher to inform a DC in order to develop a NOE for the learner. A limited selection of questions is shown in the questionnaire (2), with each question relating to a specific CLT strategy or heutagogical capability. In this figure, the sample questions 1–5 in the questionnaire relate to specific CLT strategies and questions 6–8 relate to aspects of heutagogical capability of the learner.

The first person reference to the learner for this questionnaire indicates the integration of self-management skills with CLT (Eitel, Bender & Renkl, 2020; Mirza, Agostinho, Tindall-Ford, Paas & Chandler, 2020). The inclusion of self-management skills is driven by the notion that less guidance will be needed by learners who can self-mange extraneous cognitive load in learning materials and students are provided with explicit instructions on how to improve learning design (Eitel, Bender & Renkl, 2020, p. 170).

Moreover, it is predicted that learners with insight into the purpose and uses of CLT strategies will be able to participate more fully in DC as well as estimating their time to mastery for NOEs.

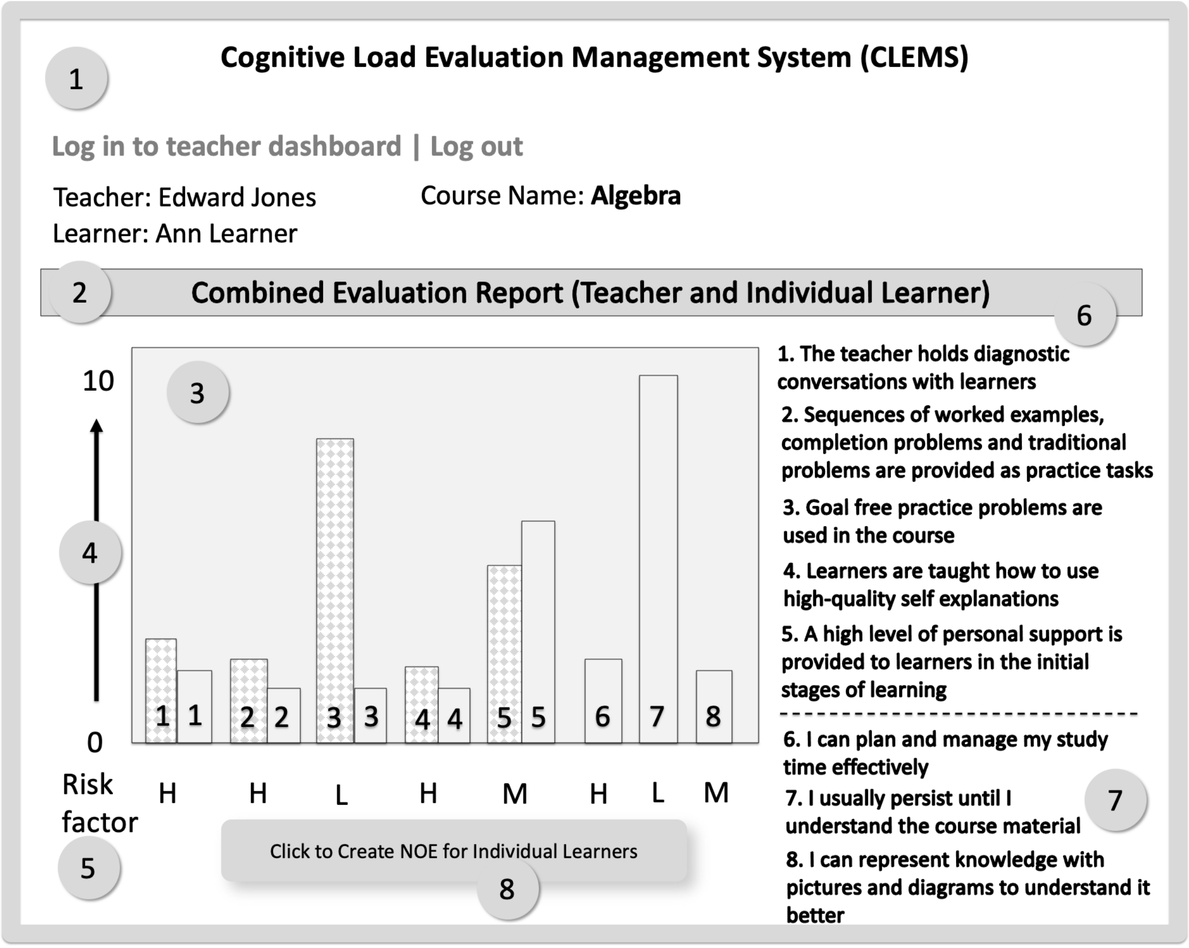


Figure 10.15 This figure shows the combined reports by the teacher and the learner

Notes: The teacher's course evaluation (1–5, patterned bars) is alongside the learner's response in the email questionnaire (10.4.2). In questions 1–5 the teacher and the learner are responding to the same parameters of the course.

Questions 6-8 reflect the learner's response to heutagogical questions about self-determined learning capability. The purpose of this comparison is to conduct a risk analysis (8) based on the alignment of learning design within the course to the learning needs of learners. For example, the strengths of the learning design of the course are: point (3) the use of goal-free practice problems and (5) a medium level of personal support.

In addition, the learner has indicated a personal quality of persistence to understand the course materials. However, the graphical comparison also shows the following weaknesses of the course in terms of meeting the needs of the learner: low levels of teacher–learner communication (1), low use of worked example and self-explanation strategies (2) and (4). In addition, the learner has declared poor time-management skills in terms of study and a low level of skill in knowledge representation through pictures and diagrams.

This information will form the basis of the DC and for the teacher to design a NOE to strengthen the course for the individual learner. As previously discussed, it is advised for a single variable to be modified within the course for each NOE. An exception to this recommendation is in the case of worked examples which are closely related to self-explanations. After the NOE has been implemented and the impact of the modification evaluated, further iterations of the evaluation cycle can be implemented to adjust additional strategies. For the purposes of this example, the worked example in Figure 10.3.8 will form the basis of the NOE (see 10–4 - Stage 1, Stage 2 and Stage 3).

10.6 Focus Group 3

10.6.1 Introduction

The third focus group was titled Trialling a prototype of the evaluation instrument (CLEMS). The data-gathering instruments provided to participants (Appendix K) were designed to elicit responses from experienced educators who could evaluate the potential usefulness of CLEMS in their own educational contexts.

Invitations to potential participants were distributed via email through inter-departmental networking coordinated by the lead study supervisor as well as via the personal network of the researcher. For this focus group, similar procedures were used as in the first two focus groups (Appendix M). Relevant information was made available for potential participants via the Moodle LMS instance that was set up at www.elearningdesignphd.com.

Participants in this focus group included experienced educators from the University of Adelaide as well as other tertiary institutions. The participants served as key informants on an expert panel in evaluating CLEMS. Comments arising from brainstorming, discussions and written responses were recorded (Appendix O), collated and coded using the same process that was used in Focus Groups 1 and 2.

Focus Group 3 was scheduled from 12.00 pm to 1.30 pm on 7 November 2017 in a computer laboratory in the Education Faculty of the University of Adelaide. All ethics protocols were observed and participants were provided with a full set of required forms (Appendix K) to complete.

Participants were provided with background information about CLT as well as feedback from the first and second focus groups to set the context of the current focus group.

After completing consent and other necessary forms and being provided with an introduction to the study, participants were provided the opportunity to ask questions in order to clarify their understanding of processes, procedures and terminology. The prototype software instrument was then demonstrated and discussed while participants had the opportunity to ask questions and provide written feedback and critique on the format, functionality and processes of the software.

10.6.2 Focus group procedure

The group consisted of 11 participants whose qualifications and experience qualified them as an expert panel (Appendix O). Participant roles included the following categories: academic researchers, administrators, managers, lecturers, trainers, instructional designers and a learner. CLEMS was demonstrated to all the participants, who were provided with paper-based detailed operating procedures for logging in and using the software (Appendix K). Questions regarding the usefulness of CLEMS were posed in the following three broad categories:

1. Functionalities of CLEMS
2. Content of CLEMS
3. Potential uses and usefulness of CLEMS.

The written responses by participants as well as notes taken by the researcher during the focus group were gathered. This data was coded, collated and summarised. The validity and reliability of collected data was verified through triangulation of data between research iterations and the previous two focus groups as well as between emerging knowledge sets from the three focus groups. All feedback was collated, summarised and coded (Appendix O) for identification of themes as per the process engaged in Focus Groups 1 and 2.

After the completion of the focus group, the data was stored according to university protocols.

10.6.3 Limitations of the trial

The trial was planned as a demonstration and review of the prototype instrument by the researcher, followed by a hands-on trial by participants. The demonstration and explanation of functions was successfully carried out, with participants referring to the supporting documentation provided which included step by step operating instructions.

After the demonstration of CLEMS to participants, a technical issue occurred which prevented participants from logging in to the system. This was not a university issue, but a configuration problem with the hosting server. The researcher contacted the technical help desk of the hosting server to address the problem, which took over an hour to rectify. This was more time than participants had available, so a discussion ensued about how to proceed with the trial in the light of the setback. It was agreed by participants that the explanation and demonstration had provided sufficient information to respond adequately to the information-gathering instruments. Participants were offered the opportunity to access CLEMS online post-focus group, which some expressed an interest in doing.

Despite this technical problem, all required forms were completed. Participants provided a broad range of feedback that addressed the research question regarding the use and usefulness of CLEMS within their professional educational contexts.

10.7 Key themes

Feedback was elicited from participants on the functionalities, content uses and usefulness of CLEMS.

10.7.1 Functionalities of CLEMS

All the functions included in the focus group information gathering instrument received very high ratings from participants, reflecting their value as part of CLEMS (Appendix O) and their usefulness to educators. The evaluated functionalities were as follows:

1. Using CLT as an evaluation standard
2. Improving the quality of courses in terms of evidence-based content
3. Improving the quality of learning experiences for learners
4. Adopting a systems approach to learning design evaluation to support the management of data
5. The use of a cloud based software instrument to facilitate scalability and extensibility of CLEMS
6. The provision of iterative reporting to reflect continuous improvement of learner progress
7. The provision of visualised reports on learner progress through learning analytics
8. The provision of a teacher-mediated vs. system-controlled software application i.e. supporting the use of a mediative–adaptive approach that values the teacher’s professional judgement in conducting DC and devising NOE intervention strategies for learners
9. The provision of an educative aspect for users i.e. the use of CLEMS for reflective practice by providing information regarding educational theory and practice
10. The provisions of feedback on general levels of evidence-based interventions in courses i.e. the measurement of the extent to which CLT strategies were included in courses
11. The provision of feedback on specific levels of evidence-based interventions in courses in terms of the needs of individual learners.
12. The facilitation of processes for the creation of personalised/adaptive interventions for learners (NOE)
13. The incorporation of an in-built DKD to support teachers in selecting information for

creating interventions based on CLT effects and strategies. The facilitation of long term storage of evaluation data in the system for future use and processing and data mining

14. The extensibility of CLEMS i.e. the capability of being modified or updated with new research/questions/statements
15. The usefulness of CLEMS as a training or professional development tool for educators and teachers.

In the following section, the functionalities of CLEMS are discussed in terms of participant feedback, highlighting strengths and limitations.

10.7.2 Responses from Focus Group 3 with thematic coding

The feedback responses from Focus Group 3 were coded into key categories as per Focus Groups 1 and 2 (Appendix O). The theme of the Focus Group was "Trialling a prototype of CLEMS" and the following coding system was used to classify responses from participants.

10.7.3 Results and Discussion: Summary of feedback regarding the usefulness of CLEMS

A broad range of feedback was provided by participants for consideration in the further development and implementation of CLEMS. At a systems level, CLEMS was regarded as providing teachers with a very practical process-driven tool or instrument to facilitate course and program evaluation, which could be valuable for academic institutions and training organisations. In addition, the value of CLEMS was affirmed as a tool for monitoring learning design in the light of more courses being presented online and requiring quality checking in terms of learning design.

Part of this monitoring process would include the aggregation of data for informing the design of learning interventions. This would in turn facilitate reflective practice for educators and contribute to the continuous improvement of courses.

However, a caveat was presented that educators should ensure that they are comparing "apples with apples" in terms of evaluating the impact of courses i.e. comparing like interventions for similar learner profiles. It would also be important, as a useability factor, for CLEMS to be integrated into Learning Management Systems in large institutions (a capability that has been designed into CLEMS through Learning Tools Interoperability) so that it could run seamlessly alongside the current technologies in use.

Feedback from participants indicated that the use of CLEMS would require the provision of training in the background knowledge of CLT for both instructors and learners. This implied that induction and ongoing professional development in the use of CLEMS would be necessary for its successful implementation i.e. pre-learning sessions for educators to operate CLEMS within their own teaching environments. Part of this training would need to include the introduction of users to the language and terminology arising from CLT, which might be unfamiliar to many.

In addition, educators would require the development of their expertise in the application of CLT effects, for example, how to design goal-free problems (or how to adapt existing problems to a goal-free format) in order to facilitate schema development for learners by reducing extraneous cognitive load during instruction. Under these conditions, training in the use of CLEMS could serve a valuable role in upskilling teachers in evidence-based teaching, learning and evaluation practices. Adequate professional development and support would also be necessary for the successful and sustainable use of CLEMS in the long term.

Participants also noted that CLEMS would be useful 'for academic staff to monitor and visualise the impact' of courses on learner outcomes, but there would also be a time commitment required for implementing CLEMS. This factor indicated that the adoption of CLEMS would need to be part of a management-level implementation strategy. The point was raised that peer assessed components could reduce 'inherent issues of self-evaluation', but as observed through triangulation with Focus Group 2, it would be essential for anyone providing learners with support to have the expertise to deconstruct their expert knowledge in order to pass it on to others in a way that enabled it to be correctly reconstructed as a learning intervention. This observation shed light on a potential weakness associated with peer tutoring that is unmonitored or has low levels of monitoring, which could cause new learners to experience confusion through inexpertly taught schema formation and automation (Kirschner, Sweller & Clark, 2006; Mayer, 2004). Ongoing research is suggested to investigate the specific parameters that strengthen learning through peer-tutoring.

In terms of the useability of CLEMS, the consideration of a "multi-panel" window would assist in users viewing data concurrently instead of having to open separate windows. Also supporting the useability factor, selected evaluation parameters could be added automatically rather than teachers having to cut and paste information to make up an individual learner plan or NOE. Contributing to greater efficiency of use, an automatically populated pre-learning questionnaire could be added for each course. The implication is that pre-course questionnaires would need to be developed by faculty, which would imply the commitment of resources to the implementation of the CLEMS. While the development of pre-course questionnaires for all courses would imply considerable investment in resources in the initial stages, it could be very beneficial for an institution to build a shared resource bank of pre- and post-course questionnaires for future use.

In summary, the usefulness of CLEMS on functional and technical levels was strongly validated through participant feedback, pointing to the perceived value for educators of a multi-functioned, integrated tool for evaluating the quality of learning design based on research arising from CLT. However, key areas were raised relating to the useability of CLEMS in practice which could impact policy and budget and could also involve the implementation of change management strategies.

Feedback on the useability of CLEMS implied the need for strategic planning in managing the implementation of CLEMS. Initially this would need to occur at an institutional policy level e.g. integrating CLEMS into existing digital learning management systems and allocation of control to teachers through appropriate training and budgetary decisions regarding the implementation of the project. The LASO model referenced in the literature review (Appendix S) could serve as a framework for the implementation of CLEMS since it deals with organisational transformation at three levels:

1. top down, implying policy level change implementation
2. bottom up, implying grass roots changes driven by teachers
3. inside out, implying that the internal changes spread out laterally between organisational silos, as well as between the organisation implementing CLEMS and other organisations.

The development of an implementation strategy for CLEMS using a model such as LASO suggests a future research direction since a strategy of this nature would provide the software as well as a validated implementation model.

10.7.4 Usefulness of CLEMS for informing learning design: Discussion

All the included functions of CLEMS received high ratings in terms of being relevant to evaluating learning design, reflecting their value as part of CLEMS and their usefulness to educators in their current form. Where overlap with functionalities of CLEMS occurred, these parameters are not repeated in this section. Appendix O provides the raw data including all responses provided by participants with coding of the responses into the five key thematic categories used in all the focus groups.

The evaluated uses of CLEMS were highly rated, with some notable emergent concepts for future iterations of CLEMS. For example, the availability of CLEMS as an app for mobile devices was rated highly, aligning with feedback from Focus Group 2 in terms of its cross-platform versatility. Linking CLEMS to social media platforms was not regarded as a particularly high priority; however, limited use of the publication of badges to celebrate learner achievements was considered a worthwhile future development.

The expansion of forms of data visualisation was rated as a medium priority. As the format of visualised data output could be very broad, future polling of users for variations in data output formats could facilitate greater usefulness of the data, since usefulness as well as useability of CLEMS have been rated as high priorities.

While the format of reporting in the CLEMS prototype has been set up for digital reports, the capability of exporting reports in .pdf format or by email was rated highly. Adding to the capability of reporting, the need to increase the number of evaluations from three in the current version of the prototype to a higher number was highly rated. This implies that teachers might wish to make use of several iterative improvements of programs over academic delivery time frames e.g. terms, semesters, years or even longer. Budgetary implications of this increased functionality would need to be considered.

The capability of CLEMS to facilitate sharing and comparing of specific practices and pedagogies amongst educators was highly rated. This functionality would allow information sharing and visualised reporting across classes, departments or even across institutions, subject to agreements and compliance with privacy protocols. The benefit of this process at a local level could decrease workloads for teachers in devising teaching interventions and at a macro level could provide management with insights into the level of evidence-based practices across the entire institute.

A key issue that arises regarding the implementation of CLEMS into educational institutions and environments is raised by the need for teachers to have a mediative–adaptive role in its implementation. This represents the pedagogical process of a personalised learning model. The following section outlines two tools for supporting teachers in guiding learners based on a more detailed analysis of the specific barriers to learning.

10.8 Tools for supporting educators in implementing CLT effects and strategies

Part of the mediative–adaptive role of the teacher is to identify opportunities to use diagnostic tools during a DC to identify and define barriers to learning. These barriers may then be addressed by developing and implementing NOEs. Two such diagnostic tools are presented in this section: the Knowledge/Heutagogy Quadrant (Figure 10.16) and the Expertise Pathway Model for Personalised Learning (Figure 10.17). These diagnostic tools support a triage process that enable teachers to conduct DC and design NOEs more effectively. NOEs are designed by teachers to represent complex element interactivity as well as to eliminate redundant instructional materials that do not contribute to schema automation (germane load) for the individual learner. The Knowledge/Heutagogy Quadrant is designed to provide teachers with the insight regarding the type of interventions that individual learners may require to overcome learning barriers or impediments and advance to higher levels of expertise (Sweller, 1999).

B

High Domain Knowledge
Low Heutagogy

1. Medium to high risk of failure or dropping out
2. Medium to high support need (tutoring, coaching, mentoring) to form and automate schemas in new knowledge domain
3. Extended supervised time needed to master knowledge and validate understanding
4. High level of training needed to build heutagogical schemas e.g. motivation, self-regulation and self-efficacy
5. Varied learning environments including “sprints” and “jogs” as part of the deliberate practice process
6. High need for CLT effects as part of the teaching strategy e.g. worked examples, goal-free problems
7. High need for situation awareness training in the knowledge domain

C

Low Domain Knowledge
High Heutagogy

1. Low to medium risk of failure or dropping out
2. Medium to high support need (tutoring, coaching, mentoring) to form and automate schemas in new knowledge domain
3. Low to medium or “just in time” supervision needed to master knowledge and validate understanding
4. Specific training needed to build heutagogical schemas
5. Expectation of medium to high rate of learning
6. Expertise reversal effect managed as there is a lower need for CLT effects as expertise develops
7. May be assigned role in peer support, leadership in tutoring others, extension and enrichment opportunities
8. Requires high situation awareness as part of learning environment

A

Low Domain Knowledge
Low Heutagogy

1. High risk of failure or dropping out
2. High support need (tutoring, coaching, mentoring) to form and automate schemas in new knowledge domain
3. Extended supervised time needed to master knowledge and validate understanding
4. Very high level of training needed to build heutagogical schemas e.g. motivation, self-regulation and self-efficacy
5. Varied learning environments including “sprints” and “jogs” as part of the deliberate practice process
6. High need for CLT effects as part of the teaching strategy e.g. worked examples, goal-free problems, removal of split attention and redundancy in learning materials
7. High need for situation awareness training in the knowledge domain

D

High Domain Knowledge
High Heutagogy

1. Low risk of failure or dropping out
2. Low learning time needed due to high prior knowledge schemas
3. “Just in time” need for support, mentoring or coaching
4. Expectation of rapid learning and low need for extended learning time
5. High self-directed learning capability
6. Expertise reversal effect managed as there is a lower need for CLT effects as expertise develops
7. May be assigned role in peer support, leadership in tutoring others, extension and enrichment opportunities
8. Requires high situation awareness as part of learning environment

Figure 10.16 Diagnostic Tool 1: The Knowledge/Heutagogy Quadrant

Notes: This tool supports teachers in determining specific levels of learner prior domain knowledge and heutagogical capability (descriptors in each quadrant are listed below in Section A–D).

The tool represented in Figure 10.16 has been designed to assist educators to triage learners in order to determine the type of support and learning environment needed for individual learners. It is therefore a tool for informing the level of personalised or individualised support needed by learners. Heutagogy or Heutagogical Capability (see Heutagogy) is defined as "self-determined learning capability" (Hase and Kenyon, 2001) and is relevant to CLT to the extent that it impacts schema formation and automation.

Heutagogy serves as an umbrella term that incorporates characteristics including the following factors that contribute to high self-directed learning capability:
a. A high motivation to learn in traditional, novel and creative ways
b. A strong capability to persevere through areas of troublesome knowledge
c. A tolerance for ambiguity and liminal states i.e. to tolerate the unknown until understanding is achieved
d. High self-efficacy levels
e. A strong self-focused locus of control
f. A strong sense of learning agency.
By using this tool, educators can gain insight into the levels of support required by learners, time frames for learning delivery and the structure of scheduled contact with learners (see Sprints and Jogs).

The characteristics of learners are defined in each the respective quadrants (A-D) as follows:

A: Low Domain Knowledge/Low Heutagogical Capability

1. High risk of failure or dropping out
2. High support need (tutoring, coaching, mentoring) to form and automate schemas in new knowledge domain
3. Extended supervised time needed to master knowledge and validate understanding
4. Very high level of training needed to build heutagogical schemas e.g. motivation, self-regulation and self-efficacy
5. Varied learning environments including "sprints" and "jogs" as part of the deliberate practice process
6. High need for CLT effects as part of the teaching strategy e.g. worked examples, goal-free problems, removal of split-attention and redundancy in learning materials
7. High need for situation awareness training in the knowledge domain

B: High Domain Knowledge/Low Heutagogical Capability

1. Medium to high risk of failure or dropping out
2. Medium to high support need (tutoring, coaching, mentoring) to form and automate schemas in new knowledge domain
3. Extended supervised time needed to master knowledge and validate understanding
4. High level of training needed to build heutagogical schemas e.g. motivation, self-regulation and self-efficacy
5. Varied learning environments including "sprints" and "jogs" as part of the deliberate practice process
6. High need for CLT effects as part of the teaching strategy e.g. worked examples, goal-free problems

7. High need for situation awareness training in the knowledge domain

C: Low Domain Knowledge/High Heutagogical Capability

1. Low to medium risk of failure or dropping out
2. Medium to high support need (tutoring, coaching, mentoring) to form and automate schemas in new knowledge domain
3. Low to medium or "just in time" supervision needed to master knowledge and validate understanding
4. Specific training needed to build heutagogical schemas
5. Expectation of medium to high rate of learning
6. Expertise reversal effect managed as there is a lower need for CLT effects as expertise develops
7. May be assigned role in peer support, leadership in tutoring others, extension and enrichment opportunities
8. Requires high situation awareness as part of learning environment

D: High Domain Knowledge/High Heutagogical Capability

1. Low risk of failure or dropping out
2. Low learning time needed due to high prior knowledge schemas
3. "Just in time" need for support, mentoring or coaching
4. Expectation of rapid learning and low need for extended learning time
5. High self-directed learning capability
6. Expertise reversal effect managed as there is a lower need for CLT effects as expertise develops
7. May be assigned role in peer support, leadership in tutoring others, extension and enrichment opportunities
8. Requires high situation awareness as part of learning environment

Diagnostic Tool 2: The Expertise Pathway Model of Personalised Learning

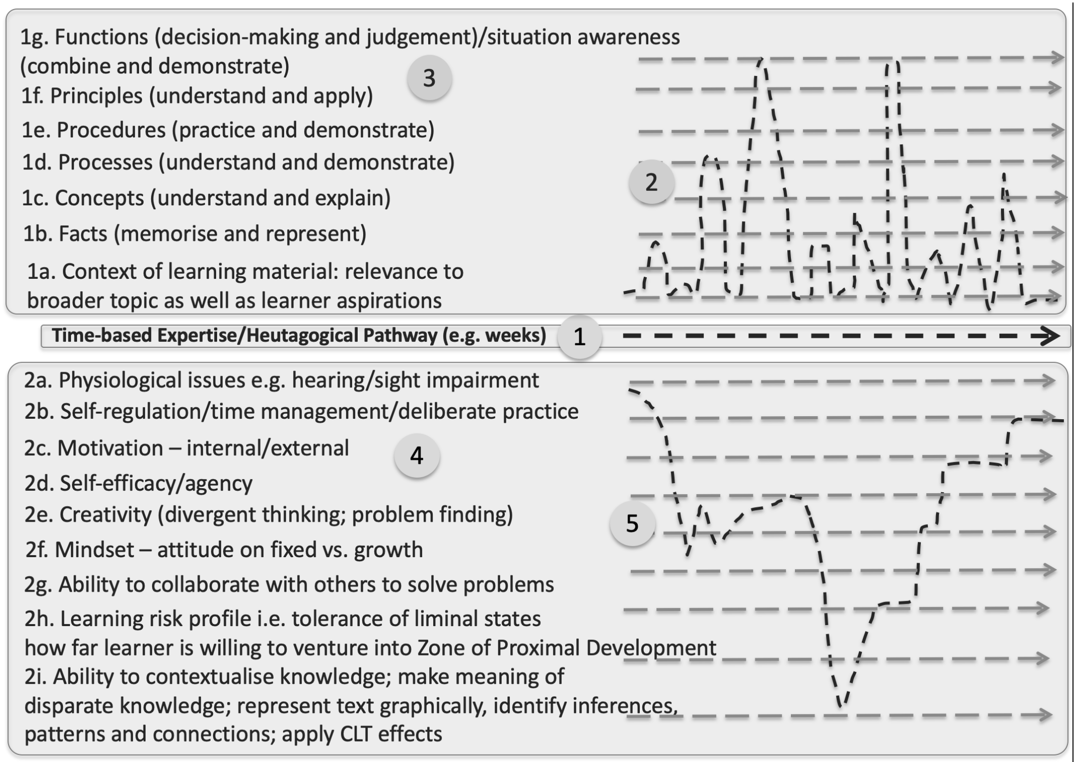


Figure 10.17 The Expertise Pathway Model of Personalised Learning

Notes: Tool for supporting teachers in identifying barriers in areas of domain-specific knowledge and heutagogical capability. The parameters of this tool may be refined or modified in future research.

The Expertise Pathway Model represents the synthesis of factors from the literature review and participant feedback from focus groups one and two that could represent barriers to learner progress in specific knowledge domains. Barriers to advancement toward expertise have been termed variously as “troublesome knowledge” (Perkins, 2006), learning “bottlenecks” (Middendorf & Pace, 2004, p. 4), “obstacles” (Middendorf & Pace, 2004, p. 3) or “impediments to schema acquisition and automation” (Sweller, 1999, p. 44). The dotted lines represent deviations from an ideal learning path caused by barriers, implying variations in time to master particular domain knowledge. The Expertise Pathway Model is one of the auxiliary tools developed for the implementation of CLEMS (see Figure 10.17). The purpose of this diagram is to support teachers in identifying specific barriers to learning, while viewing a composite and holistic list of factors that may impact the formation and automation of schemas. This model is suggested tentatively and may be represented in more useful formats in future. However, for the purposes of the current study it encapsulates the key idea that barriers to learning have an impact on the time taken for learners to progress towards expertise and the more accurately these barriers can be diagnosed in a DC, the more efficiently NOE interventions can be created to support or scaffold the learning process for individual learners to overcome these barriers. The complexity of the Expertise Pathway Model is acknowledged and future representations may split the knowledge domain factors from the heutagogical factors into separate parameters, or the model may be represented in three dimensions (knowledge, heutagogy and time) in a virtual environment. Further research needs to be conducted to determine the best format and use of this model. Alternatively, another educationally useful way to apply this model would be to simply measure and plot the seven knowledge measures and nine heutagogical measures at the start of the learning process to alert the teacher/tutor to the learner’s capabilities and difficulties for that learning period. However, at this point in the study it represents a synthesis of knowledge domain factors and heutagogical factors relevant to the advancement of the learner towards expertise and that should be given weight within a personalised model of learning. Johnsen et al. (2011) have set a precedent for this type of multifaceted model for recording a holistic view of learner progress that may be adapted for redeveloping the Expertise Pathway Model in future.

In tems of applying the Expertise Pathway Model (Figure 10.17), the ideal pathway to expertise is represented along the centre dotted line (1), where an ideal learner does not encounter troublesome knowledge that causes a deviation from this pathway. The pathway metaphor therefore suggests that there is an ideal pathway to expertise and the schema formation–automation process. However, in reality the ideal pathway is fraught with barriers depending on the prior knowledge and capability levels of the learner. Any deviation from the direct path towards expertise is assumed to take time, which should be realistically allocated within the learning environment. Points 1a–1g represent aspects of domain knowledge and points 2a-2i represent possible heutagogical factors that could impact learning negatively. (2) represents deviations from the pathway due to domains-specific knowledge barriers and (5) represents deviations from the pathway due to domains-specific knowledge barriers.
After this diagnostic tool has been used, CLT effects and strategies may be used to curate the advancement of learners to the next level of expertise through the use of NOEs. However, in order to diagnose the specific issues that the individual learner needs to address, teachers may use this model to devise chunks of knowledge that are appropriate to the learner's level of prior knowledge as well as the required level of the new knowledge (Kalyuga, 2009b). Implicit in this process is the need for learners to practice the chunk of knowledge correctly and deliberately under expert guidance and correction, until fluency of problem solving is reached as well as an increased heutagogical level that is associated with self-directed. Part of the self-directed or self-

managed learning process may include providing instruction to learners as to how to reformat tasks or content to comply with CLT strategies (Mirza, Agostinho, Tindall-Ford, Paas & Chandler, 2020).

An illustration of this process is provided from calculus, but any barrier, obstacle, threshold concept or bottleneck being experienced by a learner may be used. A learner who is experiencing a barrier to learning in solving differential calculus equations would be engaged in a Diagnostic Conversation with the teacher. The conversation would include a discussion about the following:

1. the learner's current level of knowledge of differential calculus, with the learner demonstrating expertise at their most advanced level of understanding by examples or verbal expression
2. the teacher's review of the meaning of the issue being addressed i.e. the context of the problem, its relevance to the subject as well as to the learner's application of the principle
3. identification of the specific problem area on the chart and showing it to the learner i.e. is the problem related to a fact, concept, process, procedure principle or function? i.e. application of the principle in authentic contexts in terms of decision-making, judgement and situation awareness
4. identification of any heutagogical issues related to the problem such as self- regulation, motivation, or self-efficacy
5. identification of a realistic "time-to-expertise" goal for the learner to demonstrate mastery of the chunk of knowledge
6. writing a specific goal for the learner in the form of a NOE that includes the issues discussed, and setting a realistic date by which fluency will be demonstrated.

As Figure 10.17 represents a synthesis of factors that have been identified as having an impact on the individual learner's journey towards higher levels of expertise as follows:

1a. Learning context i.e. relating the new learning to the aspirations, interests and prior knowledge of learners

1b. Facts i.e. the learner memorising and representing information fluently

1c. Concepts i.e. the learner understand and explaining conceptual knowledge fluently

1d. Processes i.e. the learner understanding and demonstrating sequential processes fluently

1e. Procedures i.e. the learner understanding and demonstrate procedural knowledge fluently

1f. Principles i.e. the learner understanding and applying abstracted principles fluently

1g. Functions i.e. the learner responding to complex environments by applying points 1a–1f

Secondly, the factors affecting heutagogical capability are below the centre line, as follows

2a. Physiological issues e.g. hearing or sight impairment

2b. Self-regulation i.e. the learner demonstrates self-regulatory and self-management skills in applying deliberate practice for extended time periods

2c. Motivation i.e. the learner demonstrates a self-generated impulse to persevere in mastering the required knowledge and skills or has externally generated motivational factors to persevere in mastering the required knowledge

2d. Self-efficacy/agency i.e. the learner demonstrates self-belief in capability to achieve learning goals and has a sense of agency or of being in control within learning environment

2e. Creativity/divergent thinking i.e. the learner demonstrates capability to generate ways for connecting new knowledge to existing knowledge, or to take intuitive leaps beyond existing knowledge

2f. Mindset i.e. attitude of fixed (unwillingness to change or adapt) or growth (openness to change) mindset

2g. Collaboration i.e. ability to collaborate with others to solve problems and learn

2h. Learning risk profile i.e. ability to understand own risk profile in learning and move beyond it to embrace new areas of learning and mastery

2i. Self-motivated ability to contextualise and make meaning of new knowledge i.e. internally-motivated capability in representing knowledge, make meaning of disparate knowledge or concepts, identify inferences, patterns and connections within knowledge, engage in decision-making, professional judgement and situation awareness, and apply CLT skills to modify content that is not compliant with CLT strategies.

Parameters on the upper level of the diagram (1a–1g) are associated with factors in learning specific content, as follows:

1. Level 1a is associated with personalising learning in specific knowledge domains according to a learner-centric model that specifies: intentionality and reciprocity (teacher intention and learner's agreement to learn), transcendence (purpose of learning) and meaning (generalisable principles, concepts or strategies from specific learning content) as requirements for effective learning (Feuerstein 2003; Feuerstein, and Jensen, 1980; Senge, 1990; Tzuriel, 2013). This level deliberately links learning to the aspirations and interests of learners
2. Levels 1b–1g, which focus on domain-specific content types, fall within the processes associated with Instructional Systems Design (Clark, 2008a; Sadler, 1989). Each type of content represents categories of content knowledge that learners encounter and how they should be learned within an expertise framework.

Parameters on the lower level of the diagram (levels 2a–2g) have arisen in the literature as key components of personalised learner-centric learning environments; these are:

a. Self-regulation – 2a (Heckhausen & Dweck, 1998)
b. Motivation – 2b (Martin, 2016)

c. Self-efficacy – 2c (Bandura, 1997a, 1997b; Rymer, 2017)

d. Agency (Annan, 2016; Gorzelsky, 2009)

e. Creativity – 2d (Csikszentmihalyi, 1996; Guilford, 1950; Robertson, 2017; Snyder, Mitchell, Bossomaier & Pallier, 2004; see also Johnson, 2017–Creativity and cognitive load)

f. Collaboration – 2e (Kirschner, Sweller, Kirschner & Zambrano, 2018; Mayer, 2005)

g. Self-motivated ability to contextualise, make meaning of knowledge (Hase & Kenyon, 2001).

This diagram represents the application of the principles of critical realism to the learning process, representing a multi-layered view of the reality of learning. This model emerged from the themes identified in the literature review with CR providing the framework for expressing it as a unified conceptual system.

10.9 Scenarios for applying CLEMS in Practice

Section 10.3 included examples of how the features and functions of CLEMS may be applied in practice for improving courses as well as creating and implementing NOEs for individual learners. A summary of steps for each of three scenarios is provided in Table 10.8 below. These scenarios are elaborated in Appendix R.

Table 10.1 Summary of course level and individual evaluation process using CLEMS

	1. Course Level Evaluation	2. Individual Learner Evaluation	3. Using CLEMS to run in situ learning experiments
1	The aim is to improve the learning design of the course by increasing the level of CLT effects and strategies	The aim is to align the learning program with the needs of individual learners using CLT effects and strategies	The aim is to use CLEMS to run experiments for testing the effectiveness of CLT effects and strategies in different learning environments
2	Teacher analyses the course using a pre-populated questionnaire	Learner completes a pre-populated questionnaire to supplement teacher's knowledge of the learner's prior knowledge	Example 1: A class may be divided into two groups (A and B) with learners randomly assigned to each group
3	Teacher views a graphic report of the level of CLT effects and strategies in the course	The teacher engages the learner in a DC to determine and record prior knowledge and heutagogical capability levels and to identify barriers to learning	Group A may engage in a learning module without specific CLT effects being integrated into the course; Group B may engage in a learning module that incorporates a NOE based on a CLT effect
4	A single strategy is selected for improvement e.g. use of worked examples	Teacher accesses the DKD and creates a NOE to address a particular barrier the learner is experiencing e.g. poor use of self-explanations	Comparative results are recorded and measured to identify effects for strengthening course delivery
5	Teacher creates a course improvement plan using tools in CLEMS	The NOE is implemented within an appropriate time frame for the learner's capabilities	NOEs that are effective in improving course delivery are used as part of the continuous improvement process of course development
6	Teacher accesses the DKD which is pre-populated with explanations of CLT strategies and their applications	The outcome of the NOE is evaluated after the learner has completed it	Alternative experiments may be set up to test or validate the use of CLT effects and strategies in different learning environments
7	Improvements are formulated into NOEs and embedded into the course e.g. modules based on worked examples	The initial questionnaire is re-taken by the learner (Step 2) to support the VC (Step 8)	Results of experimental testing may be extracted from CLEMS to foster scholarship of teaching and learning within institutions e.g. to write articles on experimental findings in educational journals
8	The course is implemented with NOEs over the specified time period	The teacher engages the learner in a Validation Conversation (VC) to determine and record the impact of the NOE intervention	n/a

9	The impact of the intervention is measured through learner achievement levels	The process is repeated at the teacher's discretion. The learner has access to reports on the entire process for self-evaluation purposes	n/a
10	The use of the particular effect is evaluated in terms of the impact on learner performance	All data arising from the NOE intervention are stored in CLEMS for future reference and ongoing personalisation of learning	n/a

10.10 Summary

The purpose of the third focus group was achieved by engaging representatives from the educational community in the form of an expert panel to review and evaluate the usefulness of CLEMS. The collated feedback from Focus Group 3 represented a broad spectrum of both affirmative validations of the functions of CLEMS as well as key ideas that could impact its usefulness and future useability.

Chapter 11 – Discussion, Conclusions and Recommendations

11.1 Introduction

The context of this study was the problem of quality evaluation of learning design in higher education in Australia, while also referencing the context of learning design quality internationally. The main research question, which was deliberately framed to facilitate open-ended exploration of the problem (Herrington et. al., 2007) was "How can the research arising from cognitive load theory inform the development of an evidence-based evaluation instrument that is useful to educational practitioners for evaluating and improving learning design?"

CLT was adopted as a standard for evaluating the quality of learning design as the literature review showed that it provided:

a. a suite of evidence-based learning strategies arising from this model that were derived through RCTs

b. a unified, functional model of human cognitive architecture as well as the mechanisms of working memory and long-term memory that are activated during formal learning.

The combination of these two factors constituted a rational standard for evaluating the extent to which teaching practices aligned with the known structure and functions of human cognitive architecture; moreover, it provided strategies for modifying learning design for alignment with human cognitive architecture where this did not occur. The study also affirmed the significant value of the CLT research base for developing more personalised learning designs.

Both parts of the research question were addressed in the study.

The first part of the question: "How can the research arising from cognitive load theory inform the development of an evidence-based evaluation instrument…?" was addressed through the literature review and the first two research iterations, the outcome of which was a theoretical model of CLEMS and its development into a working software prototype.

The second part of the question focused on determining the usefulness of CLEMS to educational practitioners as an instrument: “that is useful to educational practitioners for evaluating and improving learning design?” This part of the question was addressed through the third focus group, which consisted of expert educational practitioners who evaluated its usefulness across a broad range of parameters.

11.2 Research methodology

A DBR methodology was used to conduct the study as it supported the constructs of emergence and synthesis which were engaged throughout the study to connect diverse thematic areas that arose from the literature review. In addition, the DBR methodology aligned with the practical purpose of the study, which was to develop CLEMS for improving learning environments (Design Based Research Collective, 2003; Herrington et. al., 2007; Reeves, 2006).

The use of a DBR methodology contributed a deeper understanding of the problems associated with evaluating the quality of learning design from both a theoretical and practical perspective. This was due to the purpose of DBR, which has been intentionally designed to address practical problems in learning environments as well as to develop “sharable theories that help communicate relevant implications to practitioners and other educational designers” (Design Based Research Collective, 2003, p. 6).

The research trajectory was underpinned by the ontological framework of critical realism (CR) which provided an interpretive framework for investigating educational issues which by nature are complex and multi-faceted. CR provided a structure and framework for addressing the multi-layered and multi-mechanistic complexities involved in the process of evaluating the quality of learning design. CR accommodates the constructs of transitive and intransitive knowledge as applied to educational environments, where intransitive knowledge is represented by the established, evidence-based principles of cognitive functions related to working memory and long-term memory, as well as strategies derived from RCTs (McCarney et al., 2007). Transitive knowledge is represented as the interpretive aspects of learning that depend on the multiple variable factors present in learning environments. The adoption of transitive and intransitive constructs served to identify and categorise teaching strategies in terms of their propensity for strengthening learning.

The limitations of the study constrained exploration or exclusion of other key issues at the forefront of educational discourse. These factors included inter alia: issues of hegemony in education, advancing digital equity, cross-institutional collaboration, and rethinking the roles of educators in the light of technological and theoretical advances (Adams Becker et al., 2018). The heutagogical capabilities of learners was incorporated into the design of CLEMS as well as the diagnostic tools developed to support teachers in advancing learners to higher levels of expertise in knowledge domains. However, this inclusion does have a caveat; it is acknowledged that while heutagogical factors are at the forefront of research into the personalisation of learning, further research is required to determine the impact of its constituent parameters on CLT effects and strategies.

Finally, the literature review brought to the fore the understanding that even though a reliable and robust subjective measure cognitive load has been developed (Paas, 1992; Sweller, van Merriënboer & Paas, 2019), cognitive load has not yet been measured objectively. Key research directions in cognitive load measurement (Zhang, 2018) were identified (see Appendix G) including:

a. pupillary response measurement

b. dual task implementation

c. electroencephalography

d. ocular-motor measures (see also Ayres & Paas, 2012)

e. multimodal and data-driven cognitive load measurement.

Endeavours to measure cognitive loads objectively continue as an active research direction. Advances in both subjective and objective cognitive load measurement hold promise for gaining "greater insights into the interactions between cognitive load and instructional design" (Paas, Ayres & Pachman, 2008) as well as developing a "common knowledge base" (Zhang, 2018, p. xi) for understanding and sharing knowledge about cognitive load management during learning. As previously noted, the most reliable measure of cognitive load, which is also the least intrusive and easy to implement and measure, is the Paas Subjective Rating Scale (Paas, 1992; Paas, Ayres & Pachman, 2008; Paas et al., 2003b). It is envisaged that later iterations of CLEMS may include real-time, subjective measurement of cognitive load through the incorporation of the Paas Scale into the digital interface of CLEMS, subject to intellectual property laws. Time and development cost constraints prevented the incorporation of this feature, as well as additional complex features, into the current CLEMS prototype.

The constraints mentioned in this section did not diminish the relevance of using CLT as a framework for this study and it is expected that future research will engage with these directions more comprehensively. Naturally, not every concept within CLT was explored in this study, but its findings were selectively applied for the purpose of addressing the research question which was to inform the technological design of a learning design evaluation instrument – the goal of the study. Now that the study has been completed, the research question addressed and the prototype of CLEMS developed, the question arises: "Where to next?" In other words, what do the findings of the study signify and how might they contribute to educational contexts from this point onwards?.

11. 2 Implications of the study

The following sections discuss the significance of the study, as well as the contribution of CLEMS to key areas of educational discourse.

11.2.1 Implications: Applying cognitive load theory in learning environments

An outcome of this study was the development of a framework suitable for collating a selected knowledge base arising from CLT i.e. teaching effects or strategies, into a software architecture. The purpose of this architecture was to facilitate the implementation and monitoring of CLT effects and strategies in learning environments as an evidence-based evaluation standard (Appendix C).

The rationale for selecting CLT for this purpose was its congruence with two filtered criteria:

1. its process of using RCT experiments to determine learning effects
2. the design of teaching strategies based on these effects.its derivation from a model of human cognitive architecture.

This research addressed the challenge faced by educators wishing to include CLT in teaching programs as an evidence-based evaluation standard by providing CLT strategies in a practical and useable software format. CLEMS was designed to facilitate the implementation and monitoring of CLT strategies in complex learning environments at any scale, using cloud-based storage capabilities and database-driven technologies. A key issue that has been addressed through the functionality of CLEMS is how to implement, manage and monitor CLT-based pedagogies that have been derived from closed and controlled experimental design environments in authentic learning environments which are much more complex (Brown, 1992).

11.2.2 Technological implications of the study

The study developed the argument that CLT provides a rational base of knowledge for implementing evidence-based teaching practice due to its findings being grounded in RCT experiments. However, it is posited that without a sophisticated technological framework, it would be unlikely that CLT could advance to a level where it becomes part of mainstream educational practice. This is due to the fact that through technology not only can the distribution of the CLT knowledge base be distributed, but implemented and monitored as well.

The study adopted an information-age (Reigeluth, 2012) technological model as a useful construct for developing the new instrument; information-age signified the use of technology for a highly personalised and adaptive model of learning, a model supported by leading researchers in CLT.

CLEMS was designed to facilitate a mediative–adaptive approach to teaching and learning in which the central role of the teacher is affirmed. In this way, the technology serves pedagogical purposes and does not represent a system of centralised control; on the contrary, it is designed to draw on the expertise of teachers to exercise judgement in devising appropriate learning interventions for individual learners, informed by the knowledge base of effects and strategies arising from CLT. The technical functions of CLEMS therefore facilitate access by educators to the rich database of principles and strategies arising from CLT, which they can incorporate into their diagnoses of individual learners' barriers to learning, as well as designing learning interventions that align with the known characteristics and functions of human cognitive architecture. The technological architecture of CLEMS therefore plays a crucial role in bringing evidence-based strategies into highly complex learning environments; this is due to the capabilities of technology to facilitate the implementation, monitoring measurement and adaptation of evidence-based practices at a detailed level and at scale.

The usefulness of technology also extends to evaluating the cost-effectiveness of different approaches to the design–teaching–learning–evaluation, which suggests a possible future research direction beyond the current study.

11.2.3 Implications of the study for education in general

The key implication of the study for education is its contribution of CLEMS and the DC–NOE–VC model to support teachers in implementing, managing and monitoring evidence-based teaching strategies arising from CLT research. CLEMS is advanced as a tool for implementing an evidence-based learning design quality standard based on CLT strategies and in its ideal application, every learner would be tracked and monitored in terms of their advancement towards expertise in specific knowledge domains through NOEs that focus on germane load while minimising or eliminating extraneous load.

CLEMS contributes a method of aligning the design–teaching–learning–evaluation cycle with the cognitive architecture of learners, representing a system for devising and implementing personalised interventions for individual learners (cf. Yoem, 2013). The study also fulfilled the second principle of DBR which is to contribute to the theoretical knowledge on which the intervention has been based. The contribution of the study to theoretical knowledge is represented as the unification of evidence-based practice into pedagogical processes i.e. the DC–NOE–VC model.

The study established principles, processes and resources that can be applied to developing future iterations of the CLEMS, or alternatively, to apply the same theory-to-practice model to other theoretical learning frameworks.

In addition to the implementation and monitoring of evidence-based teaching and learning practices, the study brought a deeper understanding of the multiple levels of interactions in learning environments by positioning the study within an ontological framework of CR. For example, tools to support teachers in diagnosing levels of prior knowledge and specific learning barriers were developed (See Figures 10.16, 10.17). In summary, the key implication of the study is that educational processes can be enhanced through the structuring of learning according to a model of human cognitive architecture, where pedagogy is informed by the structure and functions as well as the strengths and weaknesses of working memory and long-term memory systems. The use of a technological framework to support this process was intrinsic to the study.

11.2.4 Implications of the study for curriculum development

Since human cognition is optimised for the attainment of expertise, as demonstrated through CLT research, this has implications for the structure and design of the curriculum. A curriculum that is evidence-based in terms of a model of expertise would be designed by subject matter experts using CTA. In addition, such a curriculum would be logically and incrementally linked in terms of domain knowledge while taking into account the prior knowledge and heutagogical capability of learners (Appendix F, Figure F3). As an expertise model of learning has some fundamental points of difference with norm-referenced models, redevelopment of curriculum would need to occur to highlight the meaning, relevance and authentic application of learning content.

In addition, an expertise-based curriculum would need to be structured from a basic level to an advanced level to provide a cohesive overview of knowledge domains to learners. Learners would need be empowered to a greater extent to analyse and focus on specific applications of discipline-based knowledge as they grow in capability. This structure would also enable learners to gain a complete view of the discipline from the perspective of its meaning, relevance and application in authentic environments and content knowledge.

A summary of implications for curriculum design based on the above principles may be expressed as follows:

1. Design the curriculum for each knowledge domain by deconstructing expert knowledge and presenting it as a continuum of increasing expertise in learning programs
2. Structure learning program for learners to attain mastery of the knowledge area, with tests or exams serving a secondary purpose to demonstrated expertise i.e. provide contextualised learning in authentic, real-world settings with multiple examples of application
3. Provide teachers with diagnostic tools and professional development to enhance their abilities to support learners and to understand how their teaching practices align with functions of human cognitive architecture i.e. every teacher needs to have an in-depth understanding of the CLT model of human cognitive architecture on which the curriculum is based so that the curriculum can be adapted to the needs of learners appropriately
4. Teach by aligning evidence-based learning effects and heutagogical effects with the learner's prior knowledge and frames of reference
5. Provide learners with appropriate support (worked examples, faded examples and problem-solving task examples) as well as expert mediation as they master the curriculum though direct instruction, avoiding pure discovery learning until they have attained a critical mass of domain-specific knowledge and the capability of implementing it in practice (Halabi, Tuovinen & Farley, 2005)
6. Track learner progress through a software system to verify progress objectively against an expertise pathway and to have early feedback on deviation from advancing towards expertise
7. Provide time flexibility and expert support for every learner to master NOEs in

knowledge domains to the point of automation

8. Avoid all constructivist approaches that place learners at risk of floundering or forming incomplete or erroneous schemas; implement this process until learners demonstrate capability of self-determined learning.

The design of a curriculum according to these principles runs counter to key tenets of a constructivist philosophy and is more suggestive of guided learning processes where learners are apprenticed, supported, tutored and mentored to the point of deep understanding of specific domain knowledge. However, it is also recognised that without sophisticated technologies and other pedagogical support tools, this approach is unlikely to be successful at scale.

11.2.5 Implications of the study for learners

The study has specific implications for learners. CLEMS and the supporting set of diagnostic tools developed through this study (Appendix F) facilitate a deeper engagement with teachers, therefore supporting a more personalised model of learning. As this model of teaching places learners on a pathway to expertise, it is intended that a greater sense of empowerment and satisfaction will be fostered in learners through conversations with teachers about curriculum, personal capability and the formulation of personal goals for advancement towards expertise. The contribution of CLEMS in this regard is that this deeper level of engagement between teachers and learners can be facilitated at scale, where every learner can engage on a pathway towards expertise, thus democratising expertise through high levels of transparency regarding learner progress, and with teachers having access to enhanced diagnostic tools for supporting learners in their progress.

CLEMS has the functionality to facilitate mandatory conversations between teacher and learner as the basis of every designed learning intervention. These may be in the form of diagnostic and validation conversations, or conversations related to any other aspect of the learning pathway. This functionality deliberately connects teachers with learners at a personal level and is designed to provide prompts for the teacher to ask questions that provide insight about the learner's prior knowledge, heutagogical capability, interests and aspirations. The design of learning interventions therefore becomes embedded as a collaborative process and the basis for ongoing conversations between teachers and learners.

A concern was raised during focus groups that contemporary teachers simply do not have the time to have personal engagement with every learner regarding their progress. A suggested method of addressing this issue that arose through the study is twofold:

1. Provide teachers with more refined methods of identifying the levels of support required by different learners (Appendix F), since levels of need are likely to occur on a continuum of demand i.e. empower teachers to apply more sophisticated methods to triage learners to discover their specific needs
2. use CLEMS to facilitate the early identification of barriers to learning. It is observed that while parallels have been drawn between medical practice and educational practice, this approach has also come under some criticism (McKnight & Morgan, 2019); these criticisms highlight the need for a cautionary approach in applying the analogy between medical practice and educational practice, but should not prevent the adoption of useful constructs from medicine that serve to advance educational practice towards its goal of continuous improvement.

An interesting implication of CLEMS is its use as a tool that potential learners could use to select the most suitable study programs for their own needs offered by different institutions. Prior to registration, learners could first use CLEMS to conduct a self-analysis of their own strengths, weaknesses, prior domain knowledge and heutagogical capability. Secondly, prospective learners could input information into CLEMS about the courses on offer from the institution. CLEMS could then generate graphical reports to illustrate the relative strengths of courses on offer in terms of the potential learner's profile. This process would require universities to release appropriate, standardised information about specific course structure, delivery and learner support levels; however, this scenario may have inherent limitations due to aspects of university information being proprietary.

In summary, the capability of CLEMS for longitudinal tracking and monitoring of learner progress means that educators are provided with a stronger base of knowledge for informing learners about their progress. This level of transparency (subject to privacy laws and protocols) is designed to bring clarity to the teaching and learning process by providing feedback to learners at a more detailed and precise level to support their advancement towards higher levels of expertise in specific knowledge domains.

11.2.6 Implications of the study for teachers

The study strongly suggests that teachers take an active role in designing learning interventions based on the model of human cognitive architecture. This is expressed through the term mediative–adaptive. Mediative represents the role the teacher takes in guiding the learner towards higher levels of expertise within the DC–NOE–VC model that implies direct, guided learning as the norm while learners increase in expertise in specific knowledge domains. The DC–NOE–VC model is supported by auxiliary tools such as the Knowledge/Heutagogy Quadrant, the Expertise Pathway Model of Personlised Learning.

The term adaptive implies that the teacher has sufficient knowledge of the learner and of human cognition to relate interventions to the learner's dynamically changing levels of knowledge, heutagogy, interests and aspirations. In practice, the process that the teacher would engage in to administer appropriately levels of interventions is likely to be characterised as a continuum, where the guidance is faded strategically as the learner forms and automates schemas. To support teachers in the process of adapting learning interventions to the learner's schema development and capability levels, some pedagogical processes have been defined more precisely e.g. levels of expertise, different quality levels of schema formation (see Section 5.8.5) and an expanded view of the steps to schema automation (see Table 5.3). These tools supplement the use of CLEMS by equipping teachers to target barriers to learning with precision.

If teachers take a leading role in the implementation of CLEMS, professional development, ongoing training and support will be required as part of implementation processes not only for the technological use of CLEMS but also for the skilled use of supplementary diagnostic tools. The DC–NOE–VC model supports the cyclical process of advancing learners towards higher levels of expertise. It is the teacher's prerogative to decide which learners require diagnostic conversations, if sufficient homogeneity exists in a cohort of learners for a diagnostic conversation to be directed to the entire cohort, or if a course should be analysed and improved using CLEMS without using the DC–NOE–VC process with learners.

11.2.7 Implications of the study for educational institutions and organisations

The success in implementing a new system, as well as its sustainability within an institution, will require guidelines in the form of policies and protocols. The nature of the policies could include the intention to personalise the learning pathway of individual learners using CLT strategies. Moreover, policy decisions would also have resourcing implications in terms of training, time and staffing as well as the cost of running CLEMS itself.

Without higher-level management engagement within educational institutions, some benefit of the system may accrue to individual classes or courses, but the real benefit of CLT strategies may be lost as a growth point for the institution as a whole e.g. some teachers may introduce CLT strategies within a class or department which would therefore only be of benefit to limited numbers of learners.

CLEMS also has implications for higher levels of policy and governance in education, for example its potential use for managing the personalisation of learning for groups of institutions, states or entire educational systems. While much more research would be required for this level of implementation, interesting possibilities have been identified during the course of the study. For example, the use of CLEMS could be expanded to manage learning pathways between school and higher education, as represented in the following figure:

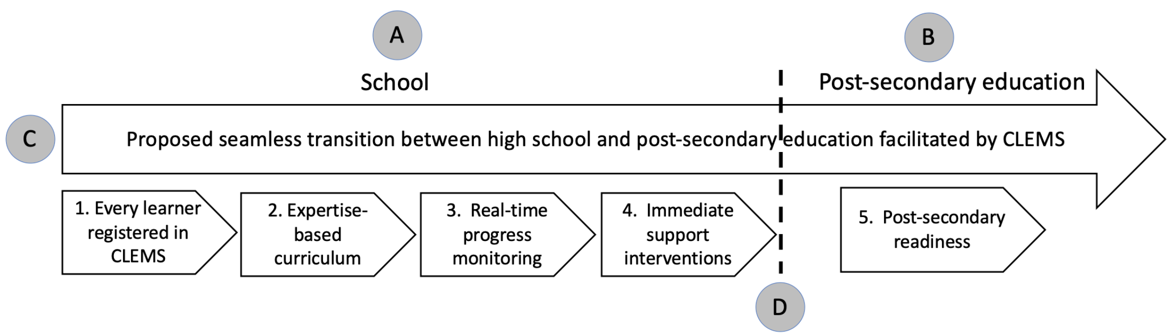


Figure 11.1 Proposed use of CLEMS for high school to post-secondary transition

Notes: This application of CLEMS is predicted to impact both schools and post-secondary educational institutions. For example higher numbers of Year 12 completions implies potentially higher numbers of learners entering post-secondary education, with better preparation for their studies. (A) shows the school stage (B) shows the post-secondary stage (C) shows the seamless transition between (A) and (B). Steps 1–4 represent the application of CLEMS at school level while (D) represents the integrated line of transition between high school and post-secondary education with (5) showing the post-secondary readiness stage.

With a curriculum focus on expertise, learners may leave school with highly developed skills in at least one discipline. For example, learners may attain a Certificate 4 or Diploma level in computer coding by dedicating 1000–2000 hours to a well-structured coding training course over the entire high school stage.

11.3 Unresolved problems and partial findings that require further investigation

11.3.1 Limitations of cognitive load theory and of its use

Not all CLT research has been implemented in the CLEMS prototype but the architecture of CLEMS has been designed to incorporate an unlimited number of parameters. Therefore, further research will need to be conducted to determine the most useful CLT effects to include based on application and further feedback from the educational community. As CLEMS is implemented in greater measure, a factor analysis process may be engaged to determine the most useful effects for different learners. In this way the knowledge base included of CLT in CLEMS will increase in usefulness based on feedback from the communities in which it is engaged.

Additionally, the aim of the study has not been to validate CLT strategies but to adopt them as an evidence-based standard. While CLT effects were originally derived from rigorous experiments with low numbers of participants, the challenges associated with the implementation of these effects at scale still remains unknown. The management of a large-scale implementation of CLEMS e.g. within a university is likely to require a team approach for implementation. This would require strategic implementation planning and all the management and technological functions required for large-scale implementation projects. Future iterations of CLEMS could include multiple levels of data code validation to mitigate potential weaknesses in the research process and outcomes.

11.3.2 Use of cognitive load theory vs. other theoretical frameworks

In this study CLT was adopted as an evidence-based learning design evaluation standard. In future studies other theoretical frameworks could also be used and researchers may use a similar technological framework to test and validate the implementation of other theoretical models. This study has established theoretical frameworks, methodology and methods that can be replicated to develop instruments based on other models.

11.3.3 Future research directions

The ongoing development of CLEMS is the key research direction for the immediate future in order to advance it from its current status to full working model. Since CLEMS has only been developed to prototype level, the first step would be to complete its development as a beta version and implement it within an organisation for testing purposes to resolve technical and useability issues, as well as to populate the DKD with the full CLT knowledge base.

Developing CLEMS beyond prototype level will have implications in terms of cost as well as finding an institution that is willing to implement it initially as a pilot study and then on a broader scale for testing within a mass learning delivery environment. Part of the plan to advance CLEMS beyond prototype level to its next level of development includes publishing journal articles that reflect its continuous improvement and application. In terms of the practical implications for large-scale implementation, the integration of CLEMS with Learning Management Systems and other systems will require further investigation. These extended functionalities may be catalogued and prioritised for the next set of iterative developments of the CLEMS protoype.

A further research direction that may shed light on academic underachievement is stereotype threat (Steele, 2010; Steele & Aronson 1995). The relationship between stereotype threat, cognitive loads and heutagogical capability has not been investigated in RCTs but presents a research direction that could shed light on underachievement by capable learners within a CLT framework.

CLEMS could also be used to investigate emerging effects within CLT to a greater extent, for example the role of imagination in learning (Leahy & Sweller, 2004, 2005; Sweller, Ayres & Kalyuga, 1011, pp. 183–186; cf. Mock, 1970–Education and the imagination). While the direct engagement of the learner's imagination has been a recurrent theme in education for over a century, continued research into the role of imagination in learning using RCTs is required to investigate its relationship to cognitive loads. The functionality of CLEMS lends itself to being used to carry out experiments of this nature e.g. to compare the achievement levels of randomly assigned groups of learners who are taught using different interventions.

Furthermore, the function of real-time subjective ratings of cognitive load can be incorporated into online learning environments. For example, a feature of CLEMS could include prompts at pre-set times for instance during or after a learning intervention, for learners to self-evaluate their subjective experience of cognitive load to provide feedback to teachers or for system administered adaptive learning pathways. The reliability of the Paas scale in measuring subjective cognitive load suggests its potential for inclusion into digital learning platforms. For example, every learning module could have an in-built Paas Scale meter that could appear as a pop-up, animated pedagogical agent (APA) at algorithmically programmed times or alternatively as a persistent feature of the learning interface. The Paas Scale APA could be programmed algorithmically to request that the learner reflect on their cognitive load and respond by clicking on a radio button or setting a slider to represent the level of cognitive load being experienced. One suggested algorithm could be based on the expected time for a learner to respond to a problem based on their prior level of performance and when this time is exceeded, the assumption that the learner is experiencing high cognitive load could trigger the APA. Further investigation is required to trial this application of the Paas Scale as a feature of CLEMS.

Another potential research direction would be to extend research into the taxonomical classification of approaches to the design–teaching–learning–evaluation cycle as developed in literature review of this study. The benefit of this type of taxonomical research could generate a deeper understanding of the theoretical rationale of different approaches.

With the transparent approach to learning progress facilitated by CLEMS deviations from the expertise pathway would be identified and corrected at a very early stage. From the perspective of higher education, universities and schools would need to consult to develop a seamless curriculum such as has been proposed in Figure 11.1 and ensure that learners are well prepared for higher education. This approach could potentially have benefits of fewer course changes by learners and lower attrition rates among learners who inadequately prepared for higher education (Burke, 2017; Crosling, Heagney & Thomas, 2009).

In summary, the recording and reporting functions of CLEMS suggest that it may be used in various settings to measure and monitor the impact of interventions which in turn may support the SoTL in different learning environments.

11.4 Closure

The rise to dominance of constructivism in the 1970s and 1980s exerted a significant impact on novice learners. As an educational paradigm, constructivism did not include the evidence-based findings arising from prior research into cognition, nor the pedagogical strategies arising from its predecessor paradigm of cognitivism. While cognitivism was critiqued as providing a depersonalised form of learning, the counter movement towards the socially driven paradigm of constructivism also rejected the explicit links between learning processes and their underpinning cognitive functions. The emergence of constructivism as a dominant educational paradigm therefore left novice learners, particularly learners from challenging social circumstances who did not have a strong base of prior knowledge, in a vulnerable position with regard to learning

(Kirschner, Sweller & Clark, 2006; Sweller, 1988).

Based on the literature review in this study, the discipline of cognitive psychology with its links to computational modelling for simulating human thought patterns has provided the strongest evidence-based, rationally derived framework for understanding and applying principles of learning design in terms of the two identified criteria of RCT-based research and a unified model of human cognitive architecture derived from historical cognitive research.

CLT research suggests that novices require an expertise learning framework with direct and explicit teaching until a critical mass of schematic domain-specific knowledge has been established in the learner's long-term memory. By no means does this imply a programmatic, dry and didactic approach to learning but a holistic, relevant and meaningful approach that engages the learner's aspirations, interests, motivations and capabilities. Only after domain-specific schemas have been well established should constructivist or discovery approaches be introduced i.e. after learners have accrued a store of expertise and heutagogical capability. Moreover, the pedagogical application of intentional, deliberate and accurate practice over extended and flexible time periods should be the normal learning process until sufficient prior knowledge has been developed.

The findings of the current study therefore suggest there needs to be a return to the link between cognitive psychology and education, with the digital systemisation and mass implementation of CLT effects and strategies. This would advance a model of learning that is evidence-based in terms of aligning teaching programs and courses with the structure and functions of human cognitive architecture.

Where to next?

A key conclusion of this study is that a gold standard of learning design needs to be established from the entire body of educational research for both validating effective teaching practices and eliminating ineffective practices in the same way that has been developed in evidence-based medical practice. Research suggests that within certain constraints, CLT provides useful information that contributes to the development of such a gold standard for education. Moreover, technology can support the goal of implementing this standard within a framework that provides a transparent view of the progress of every learner in real time in terms of knowledge acquisition and development of heutagogical capability. This goal includes the rapid implementation of targeted interventions to support learners to overcome barriers of understanding in their progress towards higher levels of expertise.

In addition, some educational problems in Australia may be addressed more specifically through this type of standard e.g. attrition rates at university and non-completion rates in high school (Deloitte, Touche & Tohmatsu, 2015). For example, extrapolating the statistics from Lamb and Huo (2017, pp. 15–23), an improvement in high school completion rates of five to ten percent per annum could populate a new university or TAFE.

This study has contributed towards the discourse on establishing an evidence-based framework for the design–teaching–learning–evaluation cycle. It has achieved this through proposing a quality standard, synthesising a broad range of theoretical and practical constructs into a coherent model, translating this model into the specifications for a new learning design evaluation instrument, then developing these specifications into a working software prototype (CLEMS). CLEMS is underpinned by a base of theoretical evidence that points to human cognitive architecture being uniquely optimised for the acquisition of expertise. The expertise model of learning arising from CLT (Sweller, Ayres & Kalyuga, 2011) is proposed as the body of knowledge that will be encapsulated within CLEMS so it can be accessed and applied by educators from a single source. It is proposed that this body of knowledge is translated into practice through the DC–NOE–VC model using deliberate and extended practice to facilitate the formation and automation of the learner's schemas. By releasing learners from the artificial stresses of time-dependent, norm-referenced learning environments that run counter to the way in which human cognitive architecture is structured, personalised learning and understanding can develop that supports deep learning and prepares learners more effectively for their future work roles.

It is hoped that this study has opened a new research direction that will advance the use of CLT as a theory-informed, evidence-based practice in education within technological architectures. The study demonstrated that current technologies may be harnessed to place every learner on a personalised track towards expertise, beginning from their own highest level of schema automation within a framework that tracks and reports on their progress in the mastery of domain-specific knowledge and heutagogical capabilities.

Bloom (1968) posited a rational, evidence-based model of education where only a negligible minority of learners do not attain mastery of their aspirational learning goals within specific knowledge domains. It is suggested that this transformation could arise through the systematic application of CLT strategies.

In summary, this thesis has addressed the research question and made a contribution to evidence-based educational practice by using the research arising from CLT to inform the design and development of an innovative cognitive load evaluation management system (CLEMS) within a technological architecture. It is hoped that in time this contribution will further advance the ongoing quest "to link existing educational theory and practice which individualises education while at the same time providing the scope and scale to provide it to ever larger numbers of students with increasing quality and relevance" (Tuovinen, 2005, p. 7).

Appendix A: Glossary

Table A.1 Glossary of terminology, definitions, abbreviations and acronyms used in this thesis

Notes: Annotations and references are provided to elaborate on the use of terminology within the research context of this thesis.

Accommodation	Accommodation refers to the process during learning where an existing cognitive schema does not reflect an accurate mental representation of a new experience or new information; in this scenario, either an adjustment to an existing schema needs to be made, or a new schema needs to be formed (Piaget, 1975; Wood, Smith & Grossniklaus, 2001).
Adaptive hypermedia learning environments	Adaptive hypermedia learning environments accommodate learner characteristics and knowledge levels (see Heutagogy) into an individualised, explicit learner model. This model is used as a framework to adapt interactions to learner needs and characteristics. This may occur by providing dynamically adjusted, adaptive knowledge domain content selection, variable presentation formats, or providing prompts that suggest relevant links to processes or further knowledge (Kalyuga, 2009b, p. 295).
Adaptive instructional systems, or adaptive learning systems	These are learning environments that dynamically respond to learner needs, parameters and personalised characteristics e.g. prior knowledge, affective factors, preferences, learning goals or aspirations, *learning preferences, and cognitive capabilities. The result of this adaptive instructional process is the presentation of appropriate information, learning content, instructional support and monitoring of the learner’s progress towards expertise (Kalyuga, 2009b, p. 296). *In this thesis the term learning preferences is favoured over learning styles, since the construct of learning styles does not have a sufficient empirical research base to validate it (R.C. Clark, 2010; Clark & Feldon, 2005).

Advance organisers	A term associated with Ausubel’s (1960, 1978) work, advance organisers are interventions that provide meaningful links between the learner’s prior knowledge and new knowledge being taught.
Analytics	see Learning Analytics
Animated Pedagogical Agents (APA)	Animated Pedagogical Agents are characters presented on computer screens to guide learners through lessons and processes within multimedia learning environments (Moreno, 2005). APA are defined in terms of their use as partners or virtual tutors in applications and educational software (Clarebout & Heidig, 2012; Moreno, 2005). APA may incorporate effects for supporting learning processes e.g. signalling and cueing (Mayer, 2005) and advance organisers (Ausubel, 1960, 1978).
Andragogy	Andragogy is the term applied to the principles and practices of adult learning based on characteristics including increased independence, self-direction and self-motivation. The term was brought into common use in contemporary educational theory by Knowles (1950, 1975, 1984a, 1984b). Andragogy translated from Greek means: andra = “man” and “gogy” = “leading”. Andragogy is differentiated from pedagogy, which translated from Greek means: “peda” = child and “gogy” = leading” which is more directed and managed by the teacher and generally applied to teaching children (Forrest & Peterson, 2017). Within a framework of andragogy, learning is an active process of construction by the learner and is not received passively from the environment. In addition, learning is defined as an interactive process where learners interpret, integrate and transform knowledge into their experiential world (Pratt, 1993). Pedagogy–Andragogy–Heutagogy is regarded as a continuum (Blaschke, 2019; Hase and Kenyon, 2001)(see Pedagogy; Heutagogy).
Anisomorphic transfer	Learning that results in the ability of learners to transfer knowledge to novel contexts i.e. the opposite of isomorphic learning where learners are only able to transfer knowledge to similar problems. The objective of training in expertise is to

	enable learners to function effectively in applying high levels of domain-specific knowledge in novel, varied situations and contexts.
Anticipatory set	Hunter (2004) used this term to describe the activities that activate the prior knowledge of the learner in preparation for new learning. This term aligns with prior knowledge (Sweller, 1988, 1999), advance organisers (Ausubel, 1960, 1978)) and pre-learning.
a priori and a posteriori knowledge	Two philosophical categories of knowledge posited by Kant (1963, originally 1781) for differentiating between prior assumptions (a priori “what is before”, Latin) that are knowable apart from experience, as contrasted with empirical evidence arising from these assumptions that are based on experience (a posteriori “what is after”, Latin). At a philosophical level, the notion of what can be knowable is subject to various interpretations; however, the usefulness of these terms to this study are twofold and based on their broader application within education. First, they provide a vocabulary for distinguishing between the ontological assumptions on which learning theories are based and the empirical evidence arising from these assumptions. Secondly, they provide a link between theory and practice by articulating underpinning theoretical assumptions and the experiential evidence that arises from these assumptions in practice. The philosophical notion of a priori and a posteriori knowledge align with the critical realist ontological framework of this study which posits a view of reality that differentiates between the real world and the observable world (see Critical Realism).
Assimilation	The incorporation of new knowledge by learners into an existing cognitive schema (Piaget, 1975; Wood, Smith & Grossniklaus, 2001).

Assumptions of the cognitive theory of multimedia learning (CTML)	An extension to CLT by Mayer (2005) with specific application in multimedia learning environments. Three key assumptions underpin the cognitive theory of multimedia learning: a. Dual channel assumption: human memory systems contain separate channels for processing materials represented in auditory and visual formats b. Limited capacity assumption: human memory systems are limited in their capacity to process information simultaneously in each of the two channels c. Active processing assumption: humans actively engage in processes of cognitive activity to construct accurate and coherent mental representations of their experiences and of external realities (Frank, Land & Schack, 2013; Mayer, 2005, pp. 32–34).
Automaticity/ automation	Automation or automaticity (Dougherty & Johnson, 1996) is a cognitive process that occurs when chunks of knowledge are deeply, persistently and permanently embedded in the long-term memory of the learner to the point that they can be retrieved with little or no mental effort i.e. the demonstration of mastery or expertise (Schneider & Shiffrin, 1977; Sweller, Ayres & Kalyuga, 2011). Automation is usually achieved through deliberate rehearsal (see Deliberate practice) that is sustained over time with expert support; however, automation does not imply rote learning without understanding (Sweller, 1999). Automation of schemas is an integrative process that combines multiple schemas into single schemas, thereby releasing capacity in working memory. The purpose and end goal of CLT is to structure the curriculum in a way that prioritises the formation and automation of schemas during learning through specific techniques, strategies and effects.
Barrier to learning	A barrier represents knowledge that is "troublesome" (Perkins, 1999) or difficult for learners due to a lack of understanding by the learner of a key concept or principle in a specific knowledge domain. Barriers are therefore associated with cognitive

	overload, where material to be learned is constituted of high element interactivity (see Element interactivity) (Leahy & Sweller, 2020) and therefore has high intrinsic load (see Intrinsic load) for the learner. Alternatively, barriers may be experienced by learners due to high extraneous cognitive load (see Extraneous load). Barriers have an inhibiting effect on the learner's advancement towards higher levels of expertise. Barriers are associated with schema formation and automation, or dysfunctions in schema formation and automation, as a lack of prior knowledge will cause a learner to stall or flounder in their progress towards expertise; barriers are therefore blockages which require learners to pass through new portals of understanding (Meyer & Land, 2006; Middendorf & Pace, 2004), a concept termed a threshold concept (Meyer & Land, 2006) (see Level of prior knowledge).
Black box of cognition	The term black box with reference to cognition has been used in the literature as a metaphor for the hidden processes and mechanisms of cognition (Grant, 1992; Hamlyn, 1990) such as working memory and long-term memory. These processes are externally invisible, but have been validated as an inextricable part of the learning process through cognitive research and developed into a unified model of human cognitive architecture by CLT research (de Jong, 2010; Tindall-Ford, Agostinho & Sweller, 2020). Visible learning (Hattie, 2009, 2012) is a research direction for making the processes engaged in learning transparent in order to modify them to the advantage of the learner. Project Zero (2016), retrieved from https://pz.harvard.edu/projects/visible-thinking has contributed a school curriculum that focuses on the learning processes of the learner becoming visible (Collins, Brown & Holum, 1991).
Blended learning	A combination of online and face-to-face learning delivery, using synchronous and asynchronous, guided and self-directed learning delivery methods; combining face-to-face teaching with digital, virtual, electronic or multimedia learning artefacts and environments (Bonk & Graham, 2006).

Bloom’s taxonomy of educational objectives	Bloom’s taxonomy of educational objectives was developed by Bloom, Engelhart, Furst, Hill and Krathwohl (1956) and is a generally accepted hierarchy for organising learning materials from lower to higher levels of complexity i.e. knowledge, comprehension, application, analysis, synthesis and evaluation. The taxonomy was conceived in three domains: cognitive (Bloom et al., 1956), affective (Krathwohl, Bloom & Masia, 1964) and psychomotor (Romiszowski, 1999; Simpson, 1972). The cognitive domain taxonomy (Bloom et al., 1956) has arguably been the most well-known of the three domains. Anderson and Krathwohl (2001) revised the taxonomy which represents the six levels of the cognitive domain as verbal descriptors. The original 6 levels of designated objectives are compared with the new revised objectives below: (www.kent.ac.uk/brussels/handbook/taxonomy.pdf) 1. Original – Knowledge; New – Remember 2. Original – Comprehension; New – Understand 3. Original – Application; New – Apply 4. Original – Analysis; New – Analyse 5. Original – Synthesis; New – Evaluate 6. Original – Evaluation; New – Create
Borrowing and reorganising principle	The borrowing and reorganising principle is one of the five governing principles underpinning the functions of working memory and long-term memory systems as posited by CLT. In terms of cognition, all information is attained by borrowing and reorganising information from others through sensory input and communication processes such as imitation; is reorganised within long-term memory schemas and is therefore likely to be different from the borrowed schema at its source (cf. Rizzolatti & Craighero, 2004; Sweller, Ayres & Kalyuga, 2011, pp. 28–31). The pedagogical implications of the borrowing and reorganising principle for learning design are that learners should be provided with as much information as they need to build a solid based of prior knowledge in order to advance to higher

	levels of expertise. Withholding information from novices through discovery learning or problem-based learning is not supported within evidence-based research (Kirschner, Sweller & Clark, 2006; Sweller, Ayres & Kalyuga, 2011, p. 31).
Campbell Collaboration	The Campbell Collaboration (2019) "is an international social science research network that produces high quality, open and policy-relevant evidence syntheses, plain language summaries and policy briefs". The Campbell Collaboration is used in this study as a model to inform the design of an evidence-based quality standard for evaluating learning design based on CLT.
Chunking	Chunking theory (Long, Singh & Snitkof, 2005; Miller, 1956) is one of four theories related to the acquisition of expertise (Gobet, 1998; Miller, 1956). It is the most dominant theory in cognitively based education and is also the memory model on which CLT is based. Chunking theory describes how the information that enters our working memory, either from sensory memory or long-term memory, is combined and recoded into increasingly sophisticated chunks, or clusters, and stored in long-term memory for later use. Chunks may either be individual units or integrated clusters of knowledge that are processed and combined in working memory. Miller (1956, p.1) posited that working memory has a limited capacity and can only process between 5–9 chunks simultaneously, depending on the type of information being learned. Later research (Cowan, 2010, 2014) has placed this number at four chunks.
Cochrane Collaboration	The Cochrane Collaboration (2019) is a non-profit organisation whose "mission is to promote evidence-informed health decision-making by producing high-quality, relevant, accessible systematic reviews (Khan, Kunz, Kleinen & Antes, 2003) and other synthesized research evidence. Our work is internationally recognized as the benchmark for high-quality information about the effectiveness of health care" (www.cochrane.org/about-us)(see also Boland, Cherry & Dickson, 2014–Doing a systematic review).

	The significance of the Cochrane Collaboration (2019) to this study is its influence on the trend towards evidence-based practices in education as reflected in the educational literature (R.C. Clark, 2010: Evans & Benefield, 2013; Masters, 2018), particularly with regard to the use of RCTs. The Cochrane Collaboration provides useful models for evaluating levels of quality of medical research and has been adapted as a model for evaluating the quality of educational research in this study (see Campbell Collaboration).
Coding	Miles, Huberman and Saldanha (2014) describe numerous categories of codes for naming and organising research data, including: a. Descriptive coding (summarises the topic in a word or short phrase) b. In vivo coding (uses the participant's voice and expressions e.g. idiomatic phrases) c. Process coding (using gerunds, or words ending in -ing to reflect action) d. Emotion coding (labelling feelings of the participant) e. Values coding (using keywords to reflect attitudes, beliefs and values of participants) f. Evaluation coding (denoting the significance, worth or merit of a program, action or event) g. Dramaturgical coding (classification of conventions related to dramatic productions) h. Holistic coding (codes for broad categories of items) i. Provisional coding (preparatory codes that will continue to be modified or revised) j. Hypothesis coding (using a coding system generated by the researcher to evaluate a hypothesis generated by the researcher) k. Protocol coding (the use of standardised coding protocols used within a discipline) l. Causation coding (coding of causal relationships, describing why and how phenomena came about) m. Attribute coding (basic descriptive codes used in field work)

	n. Magnitude coding (qualitative or quantitative descriptions of magnitude, intensity or other size values). Descriptive coding, which summarises the topic in a word or short phrase, was selected as the most appropriate for the purposes of the current study, where key words were used to categorise and organise participant responses. Sub-coding (more than one coding reference) was used where appropriate to enrich the meaning of a category. Descriptive coding was used for focus group participant responses as well as for summarising approaches to the design–teaching–learning–evaluation in Appendix E.
Cognitive affective theory of learning with media (CALM)	A research direction posited by researchers including Brüncken, Plass and Moreno (2010, p. 262; De Bruin & van Merriënboer, 2017; Martin, 2016; Martin & Collie, 2018; Martin & Evans, 2020; Sweller & Paas, 2017) for investigating the role and impact of affective factors including motivation on cognitive load and cognitive processes during learning (Hawthorne, Vella-Brodrick & Hattie, 2019; Kalyuga, 2011b; Steele, 2010; Tindall-Ford, Agostinho & Sweller, 2020).
Cognitive architecture	Laird, Newell and Rosenbloom (1987) define cognitive architecture as providing “the foundation for a system capable of general intelligent behavior. In other words, the goal is to provide the underlying structure that would enable a system to perform the full range of cognitive tasks, employ the full range of problem-solving methods and representations appropriate for the tasks, and learn about all aspects of the tasks and its performance on them”. While the study of cognitive architecture has been used to design computational systems that can mimic human thought processes (Minsky, 1975) it is significant to this study as CLT relates the alignment of designed instructional or learning interventions to the structure and functions of human cognitive architecture as elucidated by key researchers including Bartlett (1932), Miller (1956), de Groot (1965), Atkinson and Shiffrin (1968), Simon and Chase (1973) and Paivio (1986) (Paas, Renkl & Sweller, 2003, 2004; Sweller, van Merriënboer & Paas, 1998, 2019).

Cognitive constructivism	An influential child development theory formulated by Piaget (1936), which is part of a general theory of genetic epistemology (Piaget, 1968, 1970). Key concepts in cognitive constructivism include age-related intellectual stages in children and schema formation as a learning mechanism (cf. Ültanir, 2012–Constructivism).
Cognitive economy	A cognitive processing principle that strives to achieve efficient learning with minimal cognitive effort (see Automaticity; Long-term working memory) (Mayer, 2005, p. 67). For example, three key strategies that support learning with minimal cognitive effort are: a. use of validated strategies arising from CLT research to manage loads in working memory during learning b. engagement of long-term working memory c. use of the modality effect (see Modality effect) to engage dual channels (audio and visuospatial) in working memory during learning (Mayer, 2005; Sweller, Ayres & Kalyuga, 2011).
Cognitive load	Cognitive load (CL) is a construct derived from psychological theory for understanding how learning occurs within the structures and functions of human cognitive architecture. CL is defined as the mental effort (see Intrinsic load) or load exerted on working memory when new information is integrated into long-term memory schemas (Sweller, Ayres & Kalyuga, 2011, p. 73). Working memory has a limited capacity of processing (Miller, 1956) and duration (Cowan, 2010); because of this, high element interactivity (see Element interactivity; Intrinsic load) (Leahy & Sweller, 2020) learning for novices (see Novice learner and Novice-expert differences) needs to be intentionally managed within the capacity of working memory for the successful formation and automation of long-term memory schemas. Sweller, Ayres and Kalyuga (2011, p. 58) assert that “total cognitive load, consisting of intrinsic and extraneous cognitive load, must not exceed working memory resources in order for learning to be effective".

Cognitive load theory	CLT is a unified theory of cognitive structure and functions during learning. It has a particular focus on the relationship between working memory and long-term memory in order to derive novel learning interactions that align with human cognitive architecture. CLT originated with the discovery of weak and strong learning effects during problem solving (Sweller, 1988) and explained these effects through the functions and interrelationships between working memory and long-term memory systems within human cognitive architecture. Sweller, Ayres and Kalyuga (2011, p. 68) assert that “The primary, though not sole, aim of CLT has been to devise instructional procedures that reduce extraneous cognitive load and so decrease the working memory resources that must be devoted to information that is extraneous to learning”. CLT has contributed a predictive, unified model of human cognition (de Jong, 2010; Mirza, Agostinho, Tindall-Ford, Paas & Chandler, 2020) that explains the learning processes and mechanisms governed by functions of working memory and long-term memory systems. Moreover, CLT has contributed, and continues to contribute, evidence-based strategies for designing learning interventions that align with human cognitive architecture. CLT is therefore more than a theory; it is a highly sophisticated, theoretical framework for understanding learning processes, consisting of multiple mechanisms and numerous levels of functionality derived from, and incorporating, prior historical cognitive and educational research. The theoretical framework of CLT has been used to predict learning effects and validate these effects through empirical research using RCTs (Mirza, Agostinho, Tindall-Ford, Paas & Chandler, 2020; Sweller, Ayres & Kalyuga, 2011).
Cognitive load theory effects	The specific pedagogical effects arising from CLT research that explain processes and interactions that occur within human cognitive architecture during formal learning. Effects provide explanations for learning functions and dysfunctions when optimal conditions are either provided or not provided in learning environments.

	Effects also have associated strategies for aligning learning with the structure and functions of human cognition e.g. the split-attention effect explains why spatial information and text, or auditory information and text, need to be integrated on the written page or screen to avoid cognitive overload (Sweller, Ayres & Kalyuga, 2011). CLT has a focus on novice learners who are in the process of forming and automating schemas, but also explains effects applying to learners with higher levels of expertise; CLT research strongly suggests an adaptive approach to learning which implies modifying the use of strategies as learners become more self-efficacious and attain an increasingly sophisticated base of long-term memory schemas in domain-specific expertise. Where learning is not dynamically adapted to the level of the learner as expertise is developed, the risk of the expertise reversal effect (see Expertise reversal effect) increases (Kalyuga, 2007, 2009a, 2009b; Kalyuga, Ayres, Chandler & Sweller, 2003; Kalyuga, Chandler & Sweller, 1998; Kalyuga, Rikers & Paas, 2012). Before 1998 the key CLT effects included (Sweller, van Merriënboer & Paas, 1998): a. Goal-free effect b. Worked example effect c. Completion problem effect d. Split-attention effect e. Redundancy effect f. Compound element interactivity effect g. Variability effect h. Modality effect. After 1988, the key CLT effects included (Sweller, van Merriënboer & Paas, 2019): a. Imagination effect

	b. Isolated elements effect c. Compound expertise reversal effect d. Compound guidance fading effect e. Collective working memory effect f. Compound transient information effect g. Human movement effect h. Compound self-management effect. With regard to the introduction of compound effects, Sweller, van Merriënboer and Paas (2019) explain: "The reason for not previously listing the element interactivity effect is that it is not a 'simple' effect but a so-called compound effect, which is an effect that alters the characteristics of other cognitive load effects". The range of effects demonstrates that CLT is not a static list of prescribed effects to be applied in isolation, but a model of interactive effects that require dynamic adjustment to meet the needs of individual learners as they form and automate schemas in specific knowledge domains.
Cognitive load theory strategies	The specific pedagogical practices based on CLT effects for aligning learning interventions with the structure and functions of human cognitive architecture (Sweller, Ayres & Kalyuga, 2011). Strategies include: a. goal-free problems; b. the 3-step sequence of worked examples (every step explained), completion problems (some steps explained) and traditional problems (learners do every step of complete, unscaffolded examples; c. removal of learning formats that foster spatial and temporal split-attention; d. removal of redundant materials that are unnecessary for automating schemas; e. engaging dual working memory channels (visuospatial and auditory) in working memory; f. talk-aloud protocols for engaging the self-explanation

	effect to foster deep inferences in learning interactions; g. deliberately adapting learning for the needs of individual learners to avoid the negative impact of the expertise reversal effect, etc.
Cognitive task analysis (CTA)	The purpose of CTA was originally to elicit knowledge for developing computer systems (Hoffman & Lintern, 2006, p. 204); this has been expanded to the use of recorded and coded knowledge to formulate learning pathways for novices in the same domain of expertise i.e. for curriculum design or learning design. The goal of CTA is therefore a process of eliciting problem-solving actions, attitudes and thinking processes from experts in order to devise instructional materials. CTA is aimed at eliciting both practical and cognitive steps (thought processes) by experts engaged in complex tasks to devise scope and sequence pathways for learners (Clark, Feldon, van Merriënboer, Yates & Early, 2008; Endsley, 1988). CTA is relevant to this study as CLT is an expertise-based learning framework. CTA is therefore suggested as an alternative approach to traditional curriculum design (see Chapter 11) as it: a. frames learners as growing experts b. focuses on expertise in specific knowledge domains as the basis for curriculum development c. represents a pedagogy that is aligned with the structure and functions of human cognitive architecture, which is uniquely optimised for acquiring expertise (Sweller, Ayres & Kalyuga, 2011). The psychological study of eliciting knowledge from experts through a group of techniques (Schraagen, 2006, pp. 192–193) used to deconstruct workplace practices and performance used in specific domains of expertise.
Cognitive theory of multimedia learning (CTML)	The cognitive theory of multimedia learning (CTML) is a theory of how people learn from combinations of words and pictures, based on the notion that people have separate channels for processing verbal and visual information, called the dual channels assumption. Each of the two channels can only process a limited amount of material simultaneously; called

	the limited-capacity assumption. Meaningful integration of information into learning requires the engagement of relevant cognitive processing as learning occurs; called the active-processing assumption (Mayer, 2005, p. 47).
Cognitivism	An information processing-based psychological framework, where thinking processes and the mechanisms of internal mental processing are key factors for understanding the mind and learning (Belardinelli, 2012; Miller, 1956; Miller, Galanter & Pribram, 1960; Piaget, 1924, 1926, 1932, 1936).
Competency-based learning	Competency-based learning (CBL), a criterion-referenced approach to education, is a dominant form of learning design in the vocational education and training sector. It is defined as follows: "The competency-based education (CBE) approach allows students to advance based on their ability to master a skill or competency at their own pace regardless of environment. This method is tailored to meet different learning abilities and can lead to more efficient student outcomes" (https://library.educause.edu/topics/teaching-and-learning/competency-based-education-cbe).
Complex learning	Complex learning is defined as learning that requires high element interactivity (Leahy & Sweller, 2020) within working memory (Sweller, 1988) which has limited capacity in terms of processing (Miller, 1956) and duration (Cowan, 2010). Learning that has high intrinsic cognitive load, or high element interactivity, imposes a high cognitive load on working memory, increasing the risk of cognitive overload. Working memory is represented as conscious awareness and is limited to processing between five and nine individual elements simultaneously (Miller, 1956), but more recently this has been reduced to an estimated four elements (Cowan, 2010). However, although working memory capacity has inherent limitations in terms of capacity and duration, its capacity can be amplified by strategies such as processing elements through dual audio and visuospatial channels (Baddeley & Hitch, 1974; Paivio, 1986) or by bypassing working memory through a construct known as long-term working memory (Ericsson

	& Kintsch, 1995), where complex, automated schemas are accessed and brought into working memory by retrieval cues as single elements.
Compound effects	Compound effects are differentiated from simple effects in CLT, where a compound effect "is an effect that alters the characteristics of other cognitive load effects" and which "frequently indicate the limits of other cognitive load effects" (Sweller, van Merriënboer & Paas, 2019, p. 276). Sweller, van Merriënboer and Paas (1998) originally only reported simple cognitive load effects, but the intervening years since 1998 saw CLT developing in the direction of considering the impact of effects on each other, which gave rise to the construct of compound effects (Leahy & Sweller, 2020; Sweller, van Merriënboer & Paas, 2019).
Compound element interactivity effect	Cognitive load effects that are found for high element interactivity materials are typically not found for low element interactivity materials. CLT is mainly relevant for complex learning, also termed high element interactivity learning (Sweller, van Merriënboer & Paas, 2019, pp. 266–267). However, CLT principles also explain cognitive processes for learning that incurs low interactivity, since these processes occur on a continuum e.g. the expertise reversal effect explains the effect of worked examples on both novices and learners with higher levels of expertise.
Compound expertise reversal effect	Cognitive load effects that are found for low expertise learners e.g. worked example effect, goal-free effect are typically not found or may even be reversed for high expertise learners (Sweller, van Merriënboer & Paas, 2019, pp. 266–267).
Compound guidance fading effect	Cognitive load effects that are relevant to the learner at the initial stages of extended educational programs e.g. guided problem-solving or worked examples no longer remain relevant in the later stages of the program, when learners have gained a critical mass of expertise (Renkl & Atkinson, 2003; Sweller, van Merriënboer & Paas, 2019, pp. 266–267).

Compound transient information effect	"Cognitive load effects that are found for transient information (e.g. self-pacing effect, segmentation effect, modality effect) are typically not found for non-transient or less transient information" (Leahy & Sweller, 2004; Sweller, van Merriënboer & Paas, 2019, pp. 266–267).
Compound self-management effect	"Cognitive load effects that are found for ill-designed instructional materials (e.g. material that has been formatted to induce spatial or temporal split-attention) are not found when learners are explicitly taught how to reduce the associated extraneous load" (Sweller, van Merriënboer & Paas, 2019, pp. 266–267).
Constructionism	Constructionism is a pedagogy and educational theory posited by Papert (Papert & Harel, 1991) which engages learner in experiential learning and exploration in order to create and share things that are personally relevant and meaningful. The choices made by learners play a significant role in constructionism, implying that learning may be a serendipitous side-effect of exploration, but also leave scope for learners to abandon or reinvent designs when needed. This approach poses a problem in mainstream schooling and learning environments since coverage of core concepts and ideas is driven by obligatory curriculum goals and tests (Griffin, 2019; Sabelli, 2008).
Constructivism	A prominent educational theory and philosophy of education that postulates a view of how learning occurs i.e. knowledge is constructed by the learner as opposed to being received from an external source. Constructivism posits that humans generate knowledge and meaning as a result of interactions between ideas and experiences (Glasersfeld, 2014; Matthews, 2002; Perkins, 1999).
Constructive alignment	Constructive alignment is an educational approach posited by Biggs (1987, 1989, 2011). It is described as starting with specific outcomes that students are intended to learn within a knowledge domain, with teaching and assessment being

	aligned to the outcomes. Learning is therefore constructed through activities that the students carry out; learning is expressed through the actions learners take, not actions undertaken by teachers. Within a constructive alignment model, assessment is about how well learners achieve the intended outcomes, not about how well they report back to the teacher regarding what they have been told or what they have read (www.johnbiggs.com.au/academic/constructive-alignment).
Construct validity	In social science research, construct validity is a term used to define the extent to which an instrument measures that which it asserts to measure. For example, where a concept or phenomenon is not capable of being observed directly e.g. motivation, social science uses an abstracted form of the concept or phenomenon. It is therefore important that the designers of instruments and respondents share a definition of the construct in order to ensure that the particular instrument accurately gauges the concept or phenomenon it is meant to measure (Colton & Covert, 2007).
Content validity	The term content validity in research is the extent to which an instrument is representative of the topic as well as the process that is being represented (Colton & Covert, 2007, p. 68).
Continuous improvement (CI)	Continuous Improvement is a quality improvement concept and practice arising from lean manufacturing (Deming, 1986), with a growing base of research supporting its adoption in higher education. A Continuous Improvement approach posits an incremental improvement process to a system or entity through frequent, small changes that are implemented, monitored and tracked over time, as opposed to implementing major changes in single instances (Thomas, Antony, Haven-Tang, Francis & Fisher, 2017; Yorkstone, 2016). Continuous Improvement is a sub-set of continual improvement, where improvement changes are implemented simultaneously at a number of levels (American Society for Quality, 2020).
Course	Used as a generic term to describe all formal learning programs, courses and other learning interventions.

Cueing	see Signalling or cueing principle.
Criterion-referenced assessment	Criterion-referenced tests and assessments advocated by Glaser (1963) are designed to measure student performance against a fixed set of predetermined criteria or standards i.e. concise, written descriptions of what students are expected to know and be able to do at a specific stage of their education (Glossary of Educational Reform, 2015). Criterion-referenced teaching is closely associated with outcomes-based education, mastery learning and the attainment of expertise (Amirault & Branson, 2006).
Critical realism (CR)	"Critical realism (CR) (Archer, Sharp, Stones & Woodwiss, 1998; Bhaskar, 1993, 1998, 2008, 2011; Bhaskar & Danermark, 2006; Bhaskar & Lawson, 1998) is a branch of philosophy that distinguishes between the real world and the observable world. The real cannot be observed and exists independently from human perceptions, theories, and constructions. The world as we know and understand it is constructed from our perspectives and experiences through what is observable. Thus, according to critical realists, "unobservable structures cause observable events and the social world can be understood only if people understand the structures that generate events" (Warwick University, 2016). CR is the ontological perspective developed by Roy Bhaskar (1993, 1998, 2008) which has been used in this thesis.
Deliberate practice	The concept of deliberate practice arises from studies of expertise and expert performance, where it is posited that differences between non-expert and expert performers is not determined primarily by genetic predisposition, but by lifelong, effortful and focused deliberate practice to improve performance levels in specific knowledge domains (Ericsson, Krampe & Tesch-Romer, 1993).

Design–teaching–learning–evaluation cycle	See Full cycle; or full cycle of education.
Diagnostic conversation (DC)	A Diagnostic Conversation is an interaction between a teacher and an individual learner. It is the first stage of a teacher identifying a learning barrier that is being encountered by a learner. The DC consists of an interview with the individual learner in order to target the area of troublesome knowledge that is preventing the learner from advancing to the next level of expertise. The DC is used to design a learning intervention called a node of expertise (NOE) to advance the learner to the next level of expertise in the specific knowledge domain.
Didactogeny	See Learning health status
Digital Technologically Enabled Learning Environment (DTELE)	The term DTELE is used to differentiate between environments where older, non-digital technology such as overhead projectors or calculators are used (TELEs) and DTELEs, which are typified by the use of computers and internet-based technologies. However, there is some crossover in meaning between DTELE and TELE.
Disequilibration	Disequilibration, a concept associated with Piaget's genetic epistemology (Piaget, 1968, 1970), is a cognitive state of the learner where new knowledge is out of balance with existing schemas. In this scenario, the new knowledge requires assimilation into existing schemas in order for the learner's schemas to return to a state of equilibration or balance (Piaget, 1975).
DNA	In this study, the DNA of an organisation refers to the embedded culture and strategies which manifest organically in response to the environment. This occurs through the organisation's activities to catalyse its productivity. An approach to

	management based on a DNA model views the organisation as an adaptable, living and organic entity in contrast with mechanical or mechanistic approaches based on rules and enforcement of rules (Baskin, 1998).
Double-loop learning and evaluation	Argyris and Schon (1974) and Argyris (1985, 1991, 1996, 2002, 2005) posited double loop learning as part of an action theory model called action science (Argyris, 1985; Argyris, Putnam & Smith, 1985). The usefulness of the construct of double-loop learning to this study is that it provides a framework for questioning the underpinning assumptions on which evaluation is based. CLEMS represents an embodiment of double-loop evaluation; learning outcomes as well as the underpinning learning design decisions are evaluated and tracked to inform continuous improvement.
Dynamic knowledge database (DKD)	The central database of CLEMS is called the Dynamic Knowledge Database (DKD). The DKD contains information to support educators in aligning teaching with evidence-based practices based on CLT research e.g. specific pedagogical strategies for strengthening learning for novices. The DKD also serves as repository to store learner profiles, nodes of expertise and the outcomes of the implementation of nodes of expertise for later data mining, trend analysis, as well as for supporting educators to make better informed learning design decisions for individual learners in future. Subject to privacy and sharing protocols, reports from the dynamic database can inform learning design, curriculum design and pedagogy at an institutional policy level. The dynamic nature of the database implies that it will be in a constant state of change through adding user data, as well as remaining current with the most recent research and practices arising from CLT.
Evidence-based medicine (EBM)	"Evidence-based medicine (EBM) is the conscientious, explicit, judicious and reasonable use of modern, best evidence in making decisions about the care of individual patients. Evidence-based medicine integrates clinical experience and patient values with the best available research information. It is a movement which aims to increase the use of high-quality clinical research in clinical decision making" (Masic, Miokovic & Muhamedagic, 2008). Evidence-based medicine is informed by

	the Cochrane Collaboration, which has been adapted in this study to inform the development of a learning design evaluation standard.
Ecological validity	"Ecological validity examines, specifically, whether the study findings can be generalized to real-life settings; thus ecological validity is a subtype of external validity" (Andrade, 2018). The current study has been designed for ecological validity i.e. to extend the research findings into the design and development of CLEMS for use in a broad range of contexts.
E-Learning; eLearning	E-Learning and eLearning are used to describe educational design, delivery, interactions and assessments in digital, virtual or multimedia environments or in blended learning environments. These terms are used synonymously in this study. eLearning is preferred as a standardised term, but some cited publications use variations including E-Learning, elearning and Elearning.
eLearning program attributes	The attributes of eLearning programs that CLEMS has been designed to evaluate e.g. the extent to which certain evidence-based strategies arising from CLT have been intentionally designed into courses, learning programs and learning interventions; these include strategies such as the use of the self-explanation effect or inclusion of goal-free problems.
eLearning community of practice	Any stakeholders who intentionally engage with eLearning for a stated purpose. Stakeholders may include academics who are engaged in eLearning research, organisational managers and administrators who have influence over eLearning development or management; instructional and learning designers, teachers, lecturers and trainers, and learners. In some environments, these groups of stakeholders may have minimal cross-communication, but they do constitute part of the wider community of eLearning.

Element	Elements are individual pieces or clusters of knowledge defined as chunks of information (Miller, 1956). These elements are combined in working memory and then grouped or integrated at varying levels of sophistication in long-term memory structures called schemas (Bartlett, 1932; Thorndyke & Yekovich, 1980; Sweller, 1988, 1999). The type of material being learned, as well as the prior knowledge of the learner, determines the number, size and level of interactivity of elements that contribute to the cognitive load imposed on working memory.
Element interactivity effect	Element interactivity is central to CLT due to its direct impact on the cognitive load experienced by the learner (Leahy & Sweller, 2020). Learning tasks are defined as low or high element interactivity depending on the load they impose on working memory. Tasks that require high element interactivity are said to be complex tasks and generally imply conceptual understanding as opposed to simple factual or knowledge memory tasks (van Merriënboer & Kirschner, 2018). Low element interactivity tasks can be learned with no or low level of need to refer to other elements e.g. learning a list of vocabulary words in French. On the other hand, high element interactivity tasks require reference to other elements, which may be simple or sophisticated e.g. balancing a chemical equation, which requires a high level of prior knowledge. The element interactivity effect, as with all CLT effects, is demonstrated more significantly with high element interactivity learning interactions (Leahy & Sweller, 2020; Sweller, Ayres & Kalyuga, 2011, p. 58).
Environmental organising and linking principle	The environmental organising and linking principle is one of the five governing principles underpinning the functions of working memory and long-term memory systems as described by CLT, which posits that working memory obtains information from long-term memory schemas to establish links with the environment. The environmental organising and linking principle therefore facilitates or triggers the transfer of information from long-term memory to working memory so that it can be used by working memory to respond appropriately to given environments (Sweller, Ayres & Kalyuga, 100, p. 49). Thus, the environmental organising and linking principle is the mechanism that enables people to perform appropriately

	within our environment. For example, symbols within the environment, such as written letters, trigger vast, encoded resources within long-term memory and enable us to make sense of environmental cues (Sweller, Ayres & Kalyuga, 2011 p. 49).
Epistemology	“Epistemology is an area of philosophy concerned with the nature and justification of human knowledge” (Hofer & Pintrich, 1997, p. 88).
Equilibration	Equilibration is a term used by Piaget which reflects the rebalancing of cognitive structures after accommodation has occurred within schema constructs (Piaget, 1975; Wood, Smith & Grossniklaus, 2001).
Evidence-based eLearning design	Intentionally structured online learning interventions or environments that are underpinned by a validated standard. For example, CLT strategies have been derived through randomised controlled trial experiments (Sweller, Ayres & Kalyuga, 2011).
Evidence-based practice	Evidence-based practice is a key theme in this study (APA, 2005a; Australian Society for Evidence-based Teaching, 2017; R.C. Clark, 2010; Masters, 2018). Practices based on principles arising from and underpinned by research. Other disciplines have frameworks for determining the relative value of research in terms of levels of research rigour e.g. medicine and social sciences. In this research project, evidence-based practice refers to practices arising from CLT, selected through a process adopted from the Cochrane Collaboration and Campbell Collaborations and the historical research into cognition and cognitive functions during learning.

Expertise	Four main models of expertise are evident in the literature (Gobet, 1998); CLT is based on one of the earliest models of expertise, which is the chunking model (Miller, 1956). In terms of CLT, expertise is the outcome of the learner having fully formed and automated schemas obtained through the exertion of germane cognitive load during learning. Sweller (1999) observes that schemas cause moves to be generated, signifying a forward-moving process in problem solving, as opposed to the backward-moving problem-solving process that characterises means–ends analysis, which is the default problem-solving mode for novices who have no schemas or insufficiently formed and automated schemas in the particular knowledge domain.
Expertise reversal effect	The expertise reversal effect states that instructional strategies that are very effective with less experienced learners may lose their effectiveness or have negative outcomes when imposed on more experienced learners (Kalyuga, Ayres, Chandler & Sweller, 2003). The expertise reversal is a key effect in CLT as it provides a theoretical rationale for the dynamic adjustment of learning interventions as learners progress towards higher levels of expertise in specific knowledge domains (Kalyuga, 2007).
External validity	The external validity of a study is the evaluation of whether the findings of the study can be generalised to other contexts (Andrade, 2018).
Extraneous cognitive load	Extraneous cognitive load occurs when the load imposed during learning interventions is irrelevant to the formation of long-term memory schemas. This load is imposed solely because of the instructional procedures being used and is therefore controllable in instructional design (Sweller, Ayres & Kalyuga, 2011, p. 193). The reduction of extraneous cognitive load implies the increased availability of working memory resources for processing germane cognitive load.

Factor analysis	Factor analysis is a method of condensing the data contained in many variables into just a few essential variables that encapsulate their core meaning. Factor analysis is also referred to as dimension reduction. The dimensions of gathered data can be subsumed into one or more super-variables. A common technique for achieving this is Principal Component Analysis (PCA) (Qualtrics, 2019; Statsoft, 2018).
First step diagnostic approach	The first step diagnostic approach is the pedagogical realisation of the Rapid Diagnostic Approach. Learners are presented with a task e.g. a problem to solve and given a limited time to indicate what their first step would be in solving it. Different levels of learners would respond according to their relative levels of prior knowledge. It is predicated that novices would provide a response derived from a lower schematic level, but learners with greater expertise would miss some basic steps and respond at a higher level. The principle of this approach is that a learner's initial response would be derived from their highest level of schema development (Kalyuga, 2009).
Flipped classroom, flipped learning	see Thayer method
Flounder factor	The flounder factor (Clark, 2103, pp. 6, 73, 141) is a term used to describe a situation where a novice learner has insufficient schema development to understand learning materials or to progress successfully to the next level of expertise. The result is the novice learner floundering, or stumbling without making progress. Floundering in this state may exert a negative affective impact on novice learners in the form of demotivation or demoralisation. Learners with higher levels of expertise and self-determined learning capability are predicted to demonstrate greater capacity to thrive in learning situations where the flounder factor exists i.e. their higher levels of characteristics such as self-efficacy, self-regulation, agency and perseverance will enable them to persist until they achieve understanding.

Full cycle or full cycle of education	A term introduced in this study to describe a complete pedagogical process in education, also referred in this thesis as the design–teaching–learning–evaluation cycle. The ADDIE Model (analyse, design, develop, implement, evaluate) that originated as an instructional systems design process in the US military is a commonly used construct for managing the learning design process (Branson, Rayner, Cox, Furman, King & Hannum, 1976; Molenda, 2003).
Genetic epistemology	A theory posited by Piaget (1968), which includes: a. at a macro level, the four stages of cognitive development of children b. at a micro level, the mechanisms by which intellectual growth occurs, including assimilation, accommodation, disequilibration and equilibration (Piaget, 1968; Piaget, 1975; Wood, Smith & Grossniklaus, 2001).
Germane cognitive load	Germane cognitive load is the effort devoted to processing the intrinsic level of the learning material i.e. the mental effort that is directly relevant to forming long-term memory schemas. Germane load falls into a different category than intrinsic or extraneous loads. Germane load experienced by the learner is modified by the learner's prior knowledge relative to the new information being learned. A novice may need to dedicate enormous effort to processing material of high element interactivity in a new knowledge domain; an expert in the same knowledge domain might find the same learning task extremely easy due to having amassed a rich base of prior knowledge schemas.
Goal-free effect	The goal-free effect was the first instructional effect investigated within a CLT framework. Goal-free problems occur when a conventional problem with a specific goal is replaced by a problem with a non-specific goal. In a high-school geometry example provided by Sweller (1999, pp. 64–65) quoting Owen and Sweller (1985), a typical problem was to calculate the length of one specific side of a triangle. In contrast, the same problem in goal-free format did not require students to specifically calculate this length, but used a more general wording by asking students to calculate the lengths of as many

	angles as they could (Sweller, 1999, pp. 64–65). This particular wording of the problem was demonstrated to lower cognitive load by supporting students with low levels of schema formation to calculate more sides, more accurately, with increased learning, than students directed by conventional wording. These experiments "indicate[d] that preventing novice problem solvers from using means–ends analysis resulted in fewer mathematical errors both during acquisition and on subsequent problems, including transfer problems. This provided some evidence for the contention that a means–ends strategy places a heavy load on cognitive processing capacity, which retards knowledge acquisition" (Owen & Sweller, 1985, p. 272) and "reducing the goal specificity in trigonometry problems enhances problem-solving skill" (Owen & Sweller, 1985, p. 283). Goal-free problems are sometimes called no-goal problems and the goal-free effect is sometimes referred to as the goal-specificity effect (Sweller, Ayres and Kalyuga, 2011, p. v).
Growth mindset	One of two mindsets of learners propounded by Heckhausen and Dweck (1998): a. a growth mindset, with an open attitude that embraces new learning and change b. a fixed mindset, with an inflexible attitude to change and growth. In this study, affective factors including mindset, motivation, self-efficacy, agency, self-regulation, ability to cope with liminal states are included under the umbrella term heutagogy which represents the range of factors that contribute to self-determined learning capability in learners i.e. a growth mindset.
Guidance fading effect	"The guidance-fading effect derives from the worked example effect" (Sweller, Ayres & Kalyuga, 2011, p. 142). Guidance fading describes the gradual transition from worked examples to traditional problem-solving practice by incremental steps to ensure a smooth transition and promotion of schema formation and automation. Guidance fading, which can be achieved by completion problems, represents the intermediate steps between worked examples and traditional problem solving.

Heutagogy	Heutagogy is an approach to teaching and learning where a focus is placed upon the development of learner capacity and capability (Hase & Kenyon, 2001), also referred to as self-determined learning capability. Heutagogy is posited as the next step beyond pedagogy and andragogy (self-directed learning)(Knowles, 1975) and is an approach that fosters highly autonomous and self-determined learners who are prepared for lifelong learning (cf. Vaci, Edelsbrunner, Stern, Neubauer, Bilalić & Grabner, 2019–Intelligence and practice). Heutagogy is a learner-centric approach to education, where the motivations, aspirations, capabilities and skills of learners are identified, developed and engaged in order to prepare learners to function effectively in the complexities of today's workplace within a knowledge economy. Heutagogy advocates student-centred learning and teaching strategies where the learning is directed and determined by the learner (Narayan & Herrington, 2014).
High element interactivity	see Element interactivity effect
Human cognitive architecture	The structure, functions and organisation of cognitive systems that are active during learning (Sweller, 2010). CLT (Sweller, 1988) posits a model of human cognitive architecture based on validated psychological research into learning and the cognitive systems by which learning is enabled. These components include working memory and long-term memory, as well as their interrelated functions that are activated as learners engage in learning activities e.g. schema formation and automation. While considerable historical research has been conducted into the functions of cognition during learning, CLT has drawn this research together into a sophisticated, multi-level and unified model (De Jong, 2010; Sweller, Ayres & Kalyuga, 2011, p. 242) for use in predicting learning effects by taking the loads imposed on working memory into account during learning design.
Ill-structured problems	Ill-structured problems have no clearly specified problem states or problem-solving processes or procedures e.g. discuss the different meanings of "to be or not to be" in Shakespeare's Hamlet. This contrasts with well-structured problems that have rules, well-defined problem states or procedural operators for arriving at solutions e.g. use the theory of Pythagoras to

	calculate the height of a building. In both cases “we must acquire schematically based knowledge that allows us to recognize problem types and the categories of solution moves to solve particular categories of problems irrespective of whether the problems are well structured or ill structured” (Sweller, Ayres & Kalyuga, 2011, p. 102).
Imagens	A terms used in dual coding theory model developed by Paivio (2010). This model defines mental representations in terms of two independent sub-systems: the verbal logogens (spoken, auditory, written, motor) and the nonverbal imagens (mental images, nonverbal representations). In this model, associative connections exist within each subsystem and referential connections serve as links between the two subsystems.
Imagination effect	The imagination effect (Sweller, Ayres & Kalyuga, 2011, pp. 183–191) occurs when “learning is improved by asking learners to imagine rather than study instructional material” (Anderson, 1983; Cooper, Tindall-Ford, Chandler & Sweller, 2001; Ginns, 2012; Leahy & Sweller, 2004; Tindall-Ford & Sweller, 2006). The engagement of the learner’s imagination as a teaching strategy has been investigated in a range of educational contexts including: second language teaching (Broom, 2011); nursing (Letcher, 2014; Rycroft-Malone, 2004); professional health education (Hall & Hart, 2004). Research also affirms the therapeutic value of the intentional use of the imagination (Garry & Polaschek, 2000); the engagement of the imagination of learners in teaching has been the subject of intensive recent research (Menton, 2015) as well as early educational research (McMillan, 1904; Mock, 1970; Sackett, 1934, 1935). However, despite considerable research into the engagement of imagination as a teaching strategy, no systematic pedagogy of imagination with collated strategies has yet been posited by researchers, which may suggest a possible future research direction. The imagination effect is a relatively recent effect in CLT and is related to the self-explanation effect (Sweller, Ayres & Kalyuga, 2011, pp. 187–189).

in situ	Latin term meaning “on site”. In this study in situ means actual learning environments as opposed to controlled laboratory or experimental settings. A key purpose of CLEMS is to apply and monitor the effectiveness of learning interventions arising from CLT in in situ learning environments in short, medium and long-term time structures.
Individualised learning	see Personalised learning; Adaptive guidance strategy
Information-age model of education (IA)	This construct is referenced (Perkins & Unger, 1999, p. 94; Reigeluth , 1999, p. 19) as a post-industrial model of learning delivery, characterised by technologically enabled learning environments that facilitate a highly personalised form of learning delivery. This model has been adopted as a useful place-holder for CLEMS; industrial age contrasts with traditional learning methods which are characterised by a one-size-fits-all model of teaching and norm-referenced teaching outcomes. Numerous precedents have been set for this research direction in which educational software includes adaptive and personalised characteristics (ALEKS, 2019; Knewton, 2017; Ong & Ramachandran, 2000; Palmer, 2010). Other characteristics of the IA model or paradigm include: customised time frames to suit the needs of individual learners, diversity in the range of expertise acquired by learners, collaborative learning and emotional or affective development, holistic and integrated approaches to learning that include systems thinking and the teacher as a caring mentor (Wiley, 2009, p. 391-393).
Information store principle	The information store principle is one of the five governing principles underpinning the functions of working memory and long-term memory systems posited by CLT. According to this principle, long-term memory is the source of all human expertise, knowledge and skill, including problem-solving and thinking, has no known capacity limitations and is essential to the activities of cognition that are regarded as the pinnacle of human achievement of the human mind (Sweller, Ayres &

	Kalyuga, 2011). "Expertise in high-level cognitive processes is entirely dependent on the content of long-term memory" (Sweller, Ayres & Kalyuga, 2011, p. 22).
Information Systems	Information Systems (IS) are defined as sets of interconnected technical or digital components designed to collect, organise, process, monitor, store, distribute and report on information with the aim of supporting decision-making processes, control and quality in organisations. Information systems may comprise software, hardware as well as local and wide-area networks (Bertalanffy, 1968; Bourgeois, Smith, Wang & Mortati, 2019; Branson et al., 1976; Brusilovsky, 2003; Carlsson, 2004, 2010; Gregor & Jones, 2007; Hevner, 2007; Jantsch, 1973; Rogers, 1962; Wynn & Williams, 2012).
Instructional design	The principles governing the choice of elements or processes included in online learning courses, modules, programs or instances. The deliberate planning and implementation of these elements or processes into learning programs (Reiser & Dempsey, 2012).
Instrument	The instrument refers to Cognitive Load Evaluation Management System (CLEMS), the prototype software application developed in this study in response to the research question. CLEMS has not been designed to measure cognitive loads, but to serve as a tool for evaluating the extent to which strategies arising from CLT have been designed into learning interventions or courses. CLEMS also includes a range of functionalities for managing and monitoring the implementation and continuous improvement of learning interventions or courses through the increased use of CLT effects and strategies.
Instrument's characteristics	The characteristics that have been designed into CLEMS arise from principles of CLT. CLEMS functions as a vehicle for supporting educators in the implementation, management and monitoring of CLT strategies in learning environments.

Intelligent tutoring systems	Intelligent tutoring systems engage machine learning technologies and artificial intelligence to develop educational applications. These systems are specifically designed for direct interaction with learners and are programmed to do many of the tutorial and instructional functions usually conducted by tutors or teachers. Intelligent tutoring systems are used in varied domains including mathematics, language, law, physics, medicine, and reading skills. Intelligent tutoring systems have been the subject of scholarly research for several decades (Ma, Adesope, Nesbit & Liu, 2014; Minsky, 1975). Adaptive learning, a key pedagogical concept in CLT which is aligned to the expertise reversal effect (Kalyuga, 2007; Kalyuga, Ayres, Chandler & Sweller, 2003) is closely aligned with the principles espoused in intelligent tutoring systems, where learning is dynamically adjusted to the changing levels of expertise of learners (Kalyuga, 2007, 2009a, 2009b; Kalyuga, Chandler & Sweller, 1998; Kalyuga, Ayres, Chandler & Sweller, 2003; Kalyuga, Rikers & Paas, 2012; Sweller, 2011; Webley, 2013).
Internal validity	The evaluation of the internal validity of research examines whether the study design, conduct and analysis answer the research questions without bias (Andrade, 2018).
Intrinsic cognitive load	Intrinsic cognitive load is the load imposed on working memory by the relative difficulty of material to be learned. The higher the element interactivity of the learning material (number of chunks of information to be held in working memory simultaneously), the higher the load it imposes and more difficult it is for the learner (Sweller, Ayres & Kalyuga, 2011, p. 199). The learner's prior knowledge moderates the intrinsic cognitive load, as does extraneous cognitive load (additional, unnecessary information that does not contribute to learning). De Jong (2010) noted an important premise underpinning intrinsic load; it cannot be altered by instructional treatments. Learning the English alphabet is a useful illustration of intrinsic cognitive load. The alphabet with its associated phonemes and symbols requires deep learning to gain fluency in the skill of reading. While the intrinsic level of difficulty of the alphabet cannot be reduced, some strategies can be used to

	build schemas incrementally including: part tasks or part-whole sequences (Sweller, Ayres & Kalyuga, 2011, p. 208, 211, 216); long-term working memory (Ericsson & Kintsch, 1995); modality effect (Low & Sweller, 2005); or isolated elements effect (Sweller, Ayres & Kalyuga, 2011, p. 99).
Isolated elements effect	The isolated elements effect is a strategy for the management of intrinsic cognitive load by providing learners with a scaffolded, incremental progression from basic part tasks to traditional problems where the learner completes all problem solving steps without any prompts or scaffolding. This strategy has been proven effective in supporting the formation and automation of schemas. A similar procedure called the isolated/interacting-elements effect has been used in which a sequence of isolated, non-interacting elements have been removed from the full task and prioritised for initial learning (Sweller, Ayres & Kalyuga, 2011, p. 99).
Isomorphic transfer	Isomorphic transfer of learning occurs when similarly structured problems are solved by transferring the same rules from one problem to another e.g. adding double digits.
Jogs and sprints	Terms used in this study to describe learning environments that are learner-paced (jogs) or intensively focused on deliberate practice with high levels of expert support (sprints) (Ericsson, Krampe & Tesch-Romer, 1993).
Kaizen	Associated with lean processes (Deming, 1986), kaizen is a Japanese word meaning small changes, continuous improvement, or improvement. Kaizen is both a method of reducing waste in production processes and a philosophy of incremental change. The concept of kaizen therefore aligns with the structure and functions of human cognitive architecture during learning, specifically the narrow limits of change principle. This principle affirms that learning environments should only impose small changes on schemas for novice learners, since rapid changes may induce cognitive overload. The concept

	of kaizen has recently gained increasing recognition as an important concept for learning in the classroom and for the positive transformation of educational institutions (Suarez-Barraza & Rodriguez-Gonzalez, 2015; Thomas et al., 2017).
LASO model	Leadership, academic and student ownership and readiness (LASO) (Uys, 2007, 2015) is a model of technological organisational transformation. LASO has three levels, as follows: a. top-down, consisting of leadership strategies and organisational policy b. bottom-up, consisting of academic and student ownership of systems, technology and processes c. inside-out, consisting of technological transformation implementation strategies, as well as connections between the organisation and the outside world and between the organisation and other organisations.
Lean (process)	The concept and practice of lean processes, in which the term lean refers to a process improvement system, includes lean six-sigma as a sub-set and is generally associated with manufacturing (Deming, 1986). Lean processes have recently gained increased use in higher education as a method of reducing waste at different levels (cf. Clark, 2008a, pp. 6–7; Francis, 2014; O'Reilly, Healy, Murphy & O'Dubhghaill, 2017; Thomas, Antony, Haven-Tang, Francis & Fisher, 2017; Yorkstone, 2016).
Learner	Learners, also called students, are people engaged in formal education programs or courses. Learner and student are used interchangeably in this study; however, in terms of CLT, it is not assumed that all teaching results in learning, therefore the implication of using the term learner is that consideration has been given to learning design factors that have an evidence-based rationale.
Learner profile	The learner profile is the set of learner characteristics that CLEMS has been designed to evaluate as one of its functions including: a. the learner's level of prior knowledge in specific knowledge domains

	b. the learner's heutagogical capability (self-efficacy, motivation, mindset, learning goals, career aspirations, cultural and linguistic factors, as well as other factors that influence self-determined learning) c. barriers to learning diagnosed by the teacher using specific tools to support the CLEMS evaluation process (see Appendix F).
Learning	Learning is defined within a cognitive framework as a persistent or permanent change to long-term memory schemas (Sweller, 1988, 1999). If learners engage in learning interactions and no changes occur in long-term memory, then it is assumed that learning has not occurred (Sweller, Ayres & Kalyuga, 2011, p. 24). Within CLT, the purpose of formal instructional programs is to facilitate the formation and automation of domain knowledge, or the modification of stored information in long-term memory schemas. Long-term memory is the storage repository consisting of all information that has been learned, which may include separate, rote-learned facts, through to sophisticated and complex, fully integrated concepts and procedures (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011; Sweller, van Merriënboer & Paas, 2019).
Learning analytics	The use of collected and collated data that has been gathered through learning management systems and other information-gathering systems for informing decisions regarding educational issues including trends, learning design and learner progress (Educause Learning Initiative, 2011).
Learning barrier	see Barrier to Learning; Node of Expertise; Troublesome knowledge
Learning design	This term is favoured over instructional design and is used consistently throughout the study as in CLT learning involves persistent changes to long-term memory schemas. Learning represents a cognitive change that occurs for individual learners

	through designed learning intervention and is not applied to general instructional materials, but only those that can be rationalised in terms of alignment with the functions of human cognition for particular learners.
Learning health status	Learning health status (LHS) is a term used in this study to indicate a combination of both domain-specific achievement and the affective status of individual learners as they progress towards higher levels of expertise. This term has some overlap with heutagogy to the extent that motivation, self-determination, self-efficacy and its other sub-factors exert an impact on the overall achievement of learners. LHS may be considered on a continuum. At the extreme negative side of the continuum, the status of a learner may be described by a term that arose in non-Western education: didactogeny, indicating school or learning-induced illnesses, both physical and mental, caused by inappropriate treatment of learners in educational environments (Saha & Dworkin, 2009).
Learning hierarchy technique	The learning hierarchy technique is an analytical approach described as a top-down analysis of knowledge and practice in a specific knowledge domain. It is for use by teachers or instructional designers to identify prerequisites that learners require in order to attain a particular learning objective or outcome within the specified knowledge domain (Alias, 2012).
Learning management system (LMS)	A learning management system, commonly referred to as an LMS, is a software framework and application for supporting the design, delivery, management and review of online learning courses and learner interactions. LMSs vary from simple architectures that facilitate online interactions to highly complex and adaptive learning systems that predict and automatically present appropriate materials to learners. Examples of current LMSs in use include MOODLE (moodle.com), Blackboard (blackboard.com), ALEKS (aleks.com), Canvas (instructure.com), Google Classroom (google.com) and Sakai (sakailms.org).

Learning outcome/ Outcomes-based learning	Popenici and Millar (2015) describe learning outcomes as statements of defined knowledge or skills a learner is expected to understand, know and/or demonstrate after completing a learning intervention. The Australian Qualifications Framework (2013) provides a comprehensive definition of learning outcomes: “The learning outcomes are constructed as a taxonomy of what graduates are expected to know, understand and be able to do as a result of learning. They are expressed in terms of the dimensions of knowledge, skills and the application of knowledge and skills (Australian Qualifications Framework, 2013, p. 11).
Learning record store (LRS)	An online repository that stores records of learning. https://xapi.com/overview provides the following information about the function of an LRS: people learn both formally and informally, from interactions with other people and groups, to exposure to a broad range of content and materials. Learning can happen anywhere and at any time and all learning experiences can be recorded with an LRS such as the experience API or xAPI.
Learning tools interoperability (LTI)	A standard that governs integration protocols for sharing data between software systems (www.imsglobal.org/activity/learning-tools-interoperability).
Level of prior knowledge	A learner’s level of prior knowledge is the total volume of domain-specific knowledge in their long-term memory store.
Liminal space	A liminal space has been defined (Savin-Baden, 2008, 2014) as the catalytic point where a learner moves from the security of the known to the insecure and ambiguous transitionary state in the journey towards new, proactive learning. A liminal requires perseverance and resilience on the part of the learner to transition from old to new ways of thinking and conceptualising knowledge.

Load Reduction Instruction (LRI)	Load Reduction Instruction (LRI) is a CLT-based pedagogical framework developed by Martin (2016) for sequencing explicit teaching and guided discovery with a focus on enhancing the motivation, engagement, learning and achievement outcomes of learners. LRI consists of five principles:1. reducing the level of difficulty of content in the initial stages of learning 2. provision of scaffolding and instructional support 3. sufficient structured practice 4. corrective feedback as well as guidance for improving learning 5. independent application of skills by learners (Martin & Evans, 2020). LRI is based on the CLT model of human cognitive architecture and rationalises learning strategies by referencing the limitations and capabilities of working memory, long-term memory and cognitive loads. LRI aligns with the DC–NOE–VC process advanced in this study for applying CLT in practice.
Logogens	A term used in dual coding theory developed by Paivio (2010). This model defines mental representations in terms of two independent subsystems: the verbal logogens (spoken, auditory, written, motor) and the nonverbal imagens (mental images, nonverbal representations). In this model, associative connections exist within each subsystem and referential connections serve as links between the two subsystems.
Long-term working memory (LTWM)	Long-term working memory (LTWM) allows the rapid processing of large amounts of information that have previously been integrated into schemas. LTWM is regarded as a cognitive mechanism for bypassing the limitations of working memory (Ericsson & Kintsch, 1995; Plass, Moreno & Brünken, 2010. p. 38; Sweller, Ayres & Kalyuga, 2011, pp. 48, 53). LTWM has implications for curriculum design, since engaging this mechanism releases processing capacity in working memory.
Long-term memory schema	CLT posits that long-term memory schemas form the entire prior knowledge base of the learner and are activated or retrieved when learners engage in new learning experiences (Sweller, 1988). This activation can originate through conscious

	prompts by the teacher with the use of techniques such as advance organisers (Ausubel, 1978), brainstorming and discussions, or be activated by the learner through review and other revision techniques. A learner with a developed and automated schema has a mental representation of a fact, concept, process, procedure or principle within a specific knowledge domain. When the learner is exposed to a problem in the particular knowledge domain, the schema is activated and the learner identifies the problem type as well as the rule or rules governing its resolution.
Means–ends analysis	Means–ends analysis is a cognitive process that is activated during problem solving for novices who do not have a strong base of automated schemas in long-term memory. Means–ends analysis, also called means–ends search, is a backwards-working process where the learner tries to diminish the difference between the problem state and solution state during problem solving (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011, p. 10). "The operation of means–ends analysis (MEA) involves attempts at reducing differences between problem states and the goal state. It was paradoxically found that the more problem solvers knew of the goal state, the less they learned of the problem structure during the solution process" (Sweller & Levine, 1982).
Measures of instructional efficiency	"Indicators of the relative efficiency of instructional conditions and the cognitive cost of learning generated by different ways of combining measures of performance with measures of cognitive load. High efficiency learning generally occurs under conditions of low cognitive load and high test performance, and low efficiency learning occurs under high cognitive load and low test performance" (Kalyuga, 2009a, p. 302).
Mediative–adaptive	A construct that has been designed into CLEMS: the term mediative signifies the key role of the teacher in designing adaptive learning interventions (Kalyuga, 2007, 2009a, 2009b) that align with both the learner's prior knowledge and heutagogical capability (Hase & Kenyon, 2001) profiles, as well as with the model of human cognitive architecture as

	posited by CLT. In terms of CLT, novice learners require high levels of guidance and support as schemas are formed and automated, with guidance fading as increased expertise is gained by the learner. The mediative role of the teacher has similarities with a more knowledgeable other or MKO as defined by Vygotsky (1978), where the teacher or other knowledgeable people support the learner to assimilate the knowledge encountered in the zone of proximal development (ZPD) into automated schemas.
Metacognition or metacognitive knowledge	Metacognition is defined as "awareness and understanding of one's own thought processes" (Oxford Languages. Retrieved from https://languages.oup.com/google-dictionary-en/. In terms of education, metacognition is also defined as "higher-order thinking about the cognitive processes involved in learning, such as planning and evaluating progress towards the completion of a learning task" (Macquarie Dictionary, 2017.)
Modality effect	The modality effect occurs to the extent that dual channels of visuospatial and auditory processing are engaged within working memory during learning. "Under certain, well-defined conditions, presenting some information in visual mode and other information in auditory mode can expand effective working memory capacity and so reduce the effects of an excessive cognitive load" (Low & Sweller, 2005).
MOODLE	MOODLE is an acronym for Modular Object Oriented Dynamic Learning Environment. MOODLE (2012) is a learning management system (LMS) developed in Australia by Martin Dougiamas based on a constructivist learning paradigm that incorporates online interactions such as forums, blogs and wikis. "Moodle is the world's open source learning platform that allows educators to create a private space online and easily build courses and activities with flexible software tools for collaborative online learning" (MOODLE, 2012).

More knowledgeable other (MKO)	An MKO represents an interpretive enabler such as a teacher or peer who serves as a mediator between the learner's current level and next higher level of knowledge, also called the zone of proximal development (Vygotsky, 1978). The gap between current knowledge and next level knowledge state also aligns with liminal space (Meyer & Land, 2006).
Motivation	With regard to learning, motivation implies self-directed (intrinsic) drive or externally directed drive to pursue and remain engaged in deepening one's knowledge in a specific knowledge domain. The role of motivation is an emerging field of study in CLT research (Baars, Wijnia & Paas, 2017; Martin, 2016; Paas et al., 2009; Ryan & Deci, 2000).
Multimechanistic	A key characteristic of reality as expressed within the ontological model posited by critical realism (Bhaskar, 2008). The term "multimechanistic" refers to a view of reality that is laminated or multi-layered, consisting of the real (the potential of a system, whether realised or not), the actual (the realised potential, which may be at various levels of its full potential) and the empirical (the experience of the user of the system). The implication of this model for education is that learning cannot be satisfactorily explained in terms of simple cause and effect relationships, but requires a model that takes into account the operational mechanisms underpinning cognition in order to understand it more fully (Bhaskar & Lawson, 1998, p. ix).
Multimedia principle	This term explains the principle that "People learn more deeply from words and pictures than from words alone" (Comenius, 1657/1907; Goss, 2009; Mayer, 2005, p. 47). This basic principle has been extended to include additional principles for determining the relative effectiveness of a broad range of multimedia elements on learning which include audio, video, text, animations and graphics, as well as their combinations. Mayer's (2005) cognitive theory of multimedia learning posits evidence-based guidelines for the effective use of multimedia elements.

Narrow limits of change principle	The narrow limits of change principle is one of the five governing principles underpinning the functions of long-term memory which states that for novices, changes to long-term memory schemas occur slowly.
Node of expertise (NOE)	A NOE is a specific intervention that takes the learner's prior knowledge and heutagogical capability levels into account with the aim of advancing the learner to a higher level of expertise in a specific knowledge domain. A Node of Expertise (NOE) is a term coined in this study and forms one of the operating functions of CLEMS.
Norm-referenced assessment	Norm-referenced assessment reflects the comparative performance between a learner and an average, hypothetical student. The score of the hypothetical student is derived by comparng individual scores against the results of a group of test takers. Learners are ranked on a bell curve according to their individual distribution of scores (Reigeluth, Beatty & Myers, 2017; Shepard, 1979). Norm-referenced teaching does not have the expectation of expertise for all learners (cf. Bloom, 1968, 1984).
Novice learner	A novice learner lacks the automated long-term memory schemas required to solve problems in a specific knowledge domain and therefore resorts to the backwards-working process of means–ends analysis or means–ends search. Means–ends analysis is undesirable as a learning strategy for novices during formal learning (Sweller, 1988) as it limits effective schema building, the core function of learning.
Novice–expert differences	CLT recognises the different cognitive processes activated by novices compared with experts. Novices do not have a rich base of formed and automated schemas, therefore having no choice but to resort to the process of means–ends analysis to solve problems; because of this, problem solving is a poor learning strategy for novices, since novice learners need to dedicate limited working memory resources to solving the problem, leaving few if any resources for schema building.

Online learning	see eLearning.
Ontology	Ontology is the study of being, what is, or what exists. In the context of educational research, ontology refers to the core assumptions regarding the researcher's worldview related to the field of study. It is essential to ground research within an ontological framework as it defines the assumptions that underpin the research (Barnes, 2018). In this study, critical realism (CR) is the dominant ontological framework.
Palpation	Palpation is a form of medical examination that involves the health care provider using fingers and hands to touch and feel an organ or body part of the patient during physical examinations (https://medlineplus.gov/ency/article/002284.htm).
Part–whole teaching strategy; part–whole sequence	A part–whole teaching strategy deconstructs complex knowledge into its component parts, which are individually mastered by learners then gradually added to the holistic task (Renkl, Hilbert, Schworm & Reiss, 2007; Susilo et al., 2013; Sweller, Ayres & Kalyuga, 2011; van Merriënboer, Clark & de Croock, 2002).
Pedagogy	In this study pedagogy refers to the principles, theories and practices of education and may also refer to its original meaning as the specific teaching processes applied to teaching children (Macquarie Dictionary, 2017). The context of the use of the word in this study will define its intended meaning and application.
Personalisation (of learning); personalisation principle	Personalisation of learning has various definitions which represent ways of aligning learning interventions with the needs of individual learners. Mayer (2005, p. 201) defines the personalisation principle from a multimedia perspective as: "people learn more deeply when the words in a multimedia presentation are in a conversational style rather than formal style".

	Kalyuga (2009b, p. 221) elaborates on this view by defining personalisation as “tailoring multimedia environments to individual learner cognitive characteristics”. Within CLT, the personalisation of learning is one pedagogical response to the expertise reversal effect, which reflects the need for dynamic adaptation of learning materials to “current levels of learner task-specific expertise” (Kalyuga, 2009a, p. 221).
Practice	Practice within education is the repetition or rehearsal of facts, concepts, processes, procedures or principles for the purpose of deepening familiarity with them or automating them. Practice is a specific instructional activity (Gagné, 1985; Merrill, 2002, p. 43) that relates to training and mastery of learning materials or other processes. Practice is also associated with the notion of deliberate practice (Ericsson, Krampe & Tesch-Romer, 1993), a pedagogical activity aligned with the acquisition of expertise.
Principle of scaffolding	The term scaffolding has been attributed to Jerome Bruner (1960) to describe the process of providing gradations of support to learners as they progress towards mastery of domain knowledge and gain increasing independence in their learning. The Cambridge Handbook of the Learning Sciences (Sawyer, 2014) cites more than 45 specific foci on research and projects related to scaffolding and a Google Scholar search using the term “instructional scaffolding” brings up over 120,000 research references. Embodying the scaffolding principle, the guidance fading effect (Sweller, Ayres & Kalyuga, 2011, pp. 171–182), which is strongly associated with the worked example effect (Sweller, Ayres & Kalyuga, 2011, pp. 99–108), represents a progression from: a. learners studying and learning from fully worked examples that have been prepared by the teacher b. learners completing some steps of the problem with the teacher completing others c. learners doing traditional problem-solving examples, where they do every step involved in solving the problem.

Prior knowledge	see Prior learning
Prior learning	CLT defines prior learning as the most critical factor influencing new learning as it represents the total amount of schema development (Ausubel, 1978; Bransford, Brown & Cocking, 1999; Schulman, 1999; Sweller, 1988, 1999).
PRISM	PRISM is "a production system language designed to model cognitive processes" (Langley & Neches, 1981; Sweller, 1988, p. 264). Production systems apply different sets of inference rules i.e. setting conditions for actions to be taken if certain conditions are met. The use of PRISM by Sweller (1988) permitted processes in working memory to be modelled and better understood; in particular, why the forward-working process of schema-based learning results in a stronger learning effect than the default backwards-working process of means–ends analysis used by novices during learning.
Problem-solving practice	see Guidance fading effect
Program	Any deliberately structured learning instance or intervention, including courses or modules; an approach consisting of a set of prescribed practices (Merrill, 2002, p. 43).
Randomised controlled trial (RCT)	A RCT is a "study in which people are allocated at random (by chance alone) to receive one of several clinical interventions. One of these interventions is the standard of comparison or control. The control may be a standard practice, a placebo ('sugar pill'), or no intervention at all. Someone who takes part in a randomized controlled trial is called a participant or subject. Randomized controlled trials seek to measure and compare the outcomes after the participants receive the interventions. Because the outcomes are measured, randomized controlled trials are quantitative studies" (MedicineNet,

	2019). RCTs are conducted in different disciplines including education, with CLT effects being derived from RCTs arising from a unified model of human cognitive architecture.
Randomness as genesis principle	One of the five underpinning principles of cognition posited by CLT which asserts that "a random generate and test procedure is the ultimate source of all novelty in natural systems" (Sweller, Ayres & Kalyuga, 2011, p. 32).
Rapid diagnostic approach	The rapid diagnostic approach is the "diagnostic assessment of expertise based on rapidly determining if and how learners use their knowledge structures while approaching a specific problem or situation. The idea of the approach is to determine the highest level of organized structures a learner applies rapidly to a task or situation. More experienced learners would immediately see the task within their higher-level knowledge structures. Novices may only be able to identify some random lower-level components. Organized knowledge base in long-term memory is the main factor determining such differences" (Kalyuga, 2009b, p. 304).
Rapid verification diagnostic method	The rapid verification diagnostic method is "an alternative method that realizes the rapid diagnostic approach by presenting learners with a series of potentially possible steps at various stages of the solution procedure, and asking them to rapidly verify the correctness of these steps instead of generating the steps themselves. The method is easier to implement in online learning environments, and is also useable for relatively poorly defined tasks when solution steps could not be specified exactly in advance" (Kalyuga, 2009b, p. 304).
Real, actual and empirical	The three levels of reality posited by Bhaskar (2008, 1998) in the ontological model of critical realism which underpins this study. Critical realism posits a theory of interpretation of social science which looks to causative potentials and mechanisms within entities rather than positivist cause and effect relationships.

Recommender system	A recommender system (Lu, 2004) is an innovative model of an adaptive learning system that automatically guides system users to appropriate resources depending on their learning needs. Lu (2004, p. 1) states: "A recommender system aims to provide users with personalized online productor service recommendations to handle the increasing online information overload problem and improve customer relationship management". The design specification of CLEMS includes a recommender system for supporting teachers in identifying appropriate CLT strategies when creating learning interventions. When a teacher identifies a strategy to implement in a NOE, the Dynamic Knowledge Database can be accessed to obtain information about the strategy and how it may be applied effectively, with examples provided.
Redundancy effect	The redundancy effect can occur when the different sources of information in a learning instance may be understood separately without requiring mental integration by the learner (Sweller, Ayres & Kalyuga, 2011, pp. 141–154). An example is where spoken words or written text simply re-describe a diagram that can be fully understood by a learner without needing the text to impart meaning. In this instance, the integration of the written text with the diagram or graphic is not likely to be beneficial in terms of learning.
Reliability	Both reliability and validity of research instruments describe characteristics that are psychometrically desirable (Andrade, 2018). Reliability in qualitative research seeks to validate the dependability of the research results, to determine the consistency of research processes, including the issue of whether the research questions are connected to the purpose of the study and its design (Ulin, Robinson & Tolley, 2005).
Rote learning	Rote learning occurs when learners acquire fragmented pieces of knowledge (or inert knowledge), which may result in a strong demonstration of retention performance, but poor transfer of performance to new and unfamiliar contexts (Mayer, 2005, p. 15).

Schema	A schema is a mental construct held in long-term memory that allows us to classify problems according to their solution mode, for example a chess problem or a problem in another area of knowledge. According to CLT and also historical cognitive research, schema formation and construction are central functions of learning (Bartlett, 1932; de Groot, 1965; Piaget, 1926; Sweller, 1994).
Scholarly teaching	Scholarly teaching is a term applied to the practices of educators who engage in consulting the literature of education and other relevant fields, then choose and apply appropriate knowledge, concepts and principles to guide their own teaching and the learning experiences of their students. Scholarly teaching includes the process of conducting systematic observation and recording of teaching processes, analysis of outcomes and obtaining peer evaluation of their classroom performance (Martin, 2007; Richlin, 2001; Richlin & Cox, 2004, p. 127).
Scholarship of teaching and learning (SoTL)	The terms Scholarship of Teaching and Learning (SoTL) and scholarly teaching are closely related, but differ conceptually in both intent and outcome. Scholarly teaching has the goal of affecting the actual activity of teaching and its resulting learning outcomes. On the other hand, SoTL implies a formal, peer-reviewed process which results in an expanded knowledge base for informing both teaching and learning in higher education environments (Martin, 2007; Richlin, 2001; Richlin & Cox, 2004, p. 127).
Segmentation effect/principle	This effect describes the process when people learn more deeply through multimedia messages that are presented in smaller, user-paced segments or chunks, rather than as longer, continuous units (Kalyuga 2009a, p. 305; Mayer, 2005, p. 180).

Self-explanation effect	"Students who explain examples to themselves learn better, make more accurate self-assessments of their understanding, and use analogies more economically while solving problems" (van Lehn, Jones, & Chi, 1992, p. 1). Self-explanations are activities in which learners engage in active learning and attend to the material in a meaningful way while effectively monitoring their developing understanding. The self-explanation effect is most efficacious where learners have an existing knowledge base in the subject they are learning. Self-explaining is a cognitively demanding but deeply constructive activity when it occurs at a deep, inferential level. Direct teaching and well-explained written materials can support learners in becoming strong self-explainers by avoiding shallow, descriptive explanation and generating deep-level, meaningful, relevant and novel conceptual connections (Bisra et al., 2018; cf. Chi et al., 1989; Chi et al., 1994; Kalyuga 2009a, p. 305; Mayer, 2005, p. 272; Sweller, Ayres & Kalyuga, 2011). In CLT, the self-explanation effect is associated with the Imagination effect. It is important for educators to understand the conditions under which the self-explanation effect works best, and for which students, as the quality of self-explanations determines the quality of the learning (Sweller, Ayres & Kalyuga, 2011).
Sensory memory	Sensory memory is the human memory system that enables the short-lived retention of sensory impressions after the originally experienced stimulus is no longer present (Mayer, 2005, pp. 47, 130). Sensory memory consists of iconic memory which enables the retention of visual impressions and echoic memory which enables the retention of visual memories. CLT focuses primarily on the memory systems subsequent to sensory memory i.e. working memory and long-term memory and the principles, effects, guidelines and strategies that facilitate the automation of long-term memory schemas (Sweller, 1988).
Signalling or cueing principle	"The signaling principle is that people learn more deeply from a multimedia message when cues are added that highlight the organization of the essential material" (Mayer, 2005, p. 183).

Situation awareness	Situation awareness (SA) is a quality identified as being a characteristic of expertise. SA is defined as "the perception of the elements in the environment within a volume of time and space; the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988).
SOAR	Lewis (1999, p. 2) defined the SOAR model as: "a computational theory of human cognition that takes the form of a general cognitive architecture … SOAR is a major exemplar of the architectural approach to cognitive theory, which attempts the unification of a wide range of phenomena with a single set of mechanisms, and addresses a number of significant methodological and theoretical issues common to all computational cognitive theories" (Laird, Newell & Rosenbloom, 1987). SOAR is one of the computational models developed to contribute to understanding cognitive processes.
Social presence in learning environments	Social presence is the sense of connection, community or cohesiveness that learners experience in different learning environments. Studies of multimedia and online learning environments have focused on strategies and methodologies for creating, retaining or improving social presence in order to foster greater cohesiveness and collaboration amongst learners for improving learning outcomes through deeper cognitive processing (Mayer, 2014). Studies have also focused on the impact of low levels of social presence in learning environments (Lowenthal & Dennen, 2017).
Spatial contiguity principle	A principle of learning design for reducing split-attention by displaying text and graphics in close proximity to each other; "people learn more deeply from a multimedia message when corresponding words and pictures are presented near rather than far from each other on the page or screen" (Mayer 2005, p. 183).

Spiral curriculum	Bruner (1960) posited that any concept could be taught to any learner at their current level of understanding. He used the analogy of an upward spiral to visualise a model of learning where concepts are introduced and revisited multiple times in incrementally more complex forms.
Split-attention effect	An effect identified through CLT research where poorly designed lessons cause the learners to split their auditory or visual attention between materials in different locations, thereby increasing cognitive load by having to integrate this knowledge themselves. Well designed materials effectively provide content where the learner can focus on a single place to obtain instructions (Ayres & Sweller, 2005). "The split-attention effect occurs when learners must integrate in working memory multiple sources of related information presented independently but unintelligible in isolation" (Mayer, 2005, pp. 135–146; Sweller, Ayres & Kalyuga, 2011, p. 141).
Sprints and jogs	Sprints (intensive, supported practice) and jogs (less intensive, self-paced learning) are terms adopted for use in this study to represent contrasting modes of learning, both of which are asserted as being necessary for the formation and automation of schemas. When a teacher creates a node of expertise (NOE) for a learner, a realistic time–to–mastery goal is set based on knowledge of the learner's capabilities that can include sprints and jogs. A sprint could be a short session such as a workshop with planned, intensive practice of complex knowledge, or longer bootcamp-style sessions that may run for a full day, a week or a month of intensive practice with high levels of expert support. Research into intensive learning environments called bootcamps has provided insight into alternative learning delivery formats to conventional lectures or online environments (Johnson, Wisniewski, Kuhlemeyer, Isaacs & Krzykowski, 2012).
Stereotype threat	Stereotype threat is a construct that was posited by Steele and Aronson (1995). "Stereotype threat occurs when people are at risk for living up to a negative stereotype about their group. For example, a woman may fail to reach her career goal of

	being a scientist because of how she changes her behavior in response to perceptions about her own gender" (www.learning-theories.com/stereotype-threat-steele-aronson.html). The relationship between stereotype threat and its impact on cognitive load during learning has not been investigated in randomised controlled trials, but presents promise as a research direction.
Standards for evaluating eLearning design	Numerous varying standards exist for evaluating the quality of eLearning design, but no gold standard has yet been devised with universal recognition at a peer-reviewed level. The ISO/IEC 19796-1:2005 standard provided a positive contribution towards the goal of a general standard, but was discontinued in 2005. The purpose of this standard was defined in the following way: "ISO/IEC 19796-1:2005 is only the first step towards a harmonized quality framework; the next step is to define quality instruments and metrics in order to provide a complete quality approach. It is planned to begin the work on the full quality approach as the second part of the QA activity". Retrieved from www.iso.org/standard/33934.html
Subjective ratings of cognitive load	While the objective measurement of cognitive loads is an ongoing research direction in CLT (Paas, Tuovinen, Tabbers & Van Gerven, 2003; Zheng, 2018), no reliable objective method has yet been discovered. However, reliable measures of cognitive load during learning have been validated through subjective methods. Subjective ratings of cognitive load are "measures of cognitive load that are based on the assumption that people are able to introspect their conscious cognitive processes" (Kalyuga, 2009a, p. 306; Paas, 1992; Sweller, Ayres & Kalyuga, 2011). The Paas (1992) mental effort scale of subjective cognitive load measurement, which was similar to a prior scale developed by Bratfisch, Borg and Dornic (1972), is the most strongly validated cognitive load rating scale developed to this point. In terms of this study, the development of technologically enabled learning environments (Fisher, 2010; Reigeluth, 1999) suggests that processes such as the subjective rating of cognitive load have the potential of being incorporated into online learning environments for administration in real time i.e. a feature of a learning management system could be that learners

	are prompted at set times to provide feedback regarding the levels of cognitive load they are experiencing which could trigger an alert to a teacher for support.
System/systemic approach to evaluation; systems thinking	An approach that is based on a unified model consisting of interrelated components and feedback loops between components. The systems thinking approach contrasts with traditional analysis, which studies systems by breaking them down into their separate elements. Systems thinking can be used in any area of research and has been applied to the study of “educational systems, among many others” (Bertalanffy, 1968; Rouse, 2005). Systems and systems thinking form a central role in this study which seeks to integrate components in the form of identified themes and research findings into a unified system for improving learning design and learning outcomes. CLT may be viewed as a system of dynamically interrelated memory systems and functions that govern formal learning processes.
Task analysis	Task analysis is the method used to derive competency-based learning where procedures carried out to perform work in trades and other disciplines are deconstructed into constituent parts such as elements, performance criteria, skills and knowledge (Annett & Stanton, 2000; Clark, 2008a; Farmer, 2007; Jonassen, Tessmer & Hannum, 1999; Schraagen, 2006; Standards for Vocational Education and Training Accredited Courses, 2012; Yates, 2017). Different methodological approaches to task analysis exist, such as hierarchical task analysis (Stanton, 2004). Outputs of a task analysis may include: • skill levels, education and training required by users • detailed descriptions of physical, perceptual, and cognitive activities involved with task • length of task and task variability • frequency of task • sequences of activities occurring in task

Taxonomies of learning	"Taxonomy is the process of naming and classifying things such as animals and plants into groups within a larger system, according to their similarities and differences" (www.collinsdictionary.com/dictionary/english/taxonomy) and "the study of the general principles of scientific classification" (www.merriam-webster.com/dictionary/taxonomy). Taxonomies of learning represent principle-based systems of classification and categorisation of thematically selected information that may be hierarchically arranged. For example, Bloom's taxonomy of learning objectives (Bloom et al., 1956) is thematically ordered according to three domains: cognitive, affective and psychomotor (Seaman, 2011).
Technologically enabled learning environments (TELEs)	TELEs provide learners with access to the internet using mobile and desktop devices. The term Digital Technologically Enabled Learning Environments (DTELE) has been adopted more recently to differentiate between environments where older, non-digital technology such as overhead projectors or calculators are used. These technologies have stimulated the growth of blended learning models that include both synchronous and asynchronous environments. The development of TELEs has served as a catalyst for the development of innovative learning environments. TELEs include the possibility of a "third space" (Fisher 2010, p. 1) in which increasingly social models of student interactions are facilitated, both on campus and in virtual environments.
Template theory	Template theory (Gobet, 1998; Gobet & Simon, 1996) is a model of expertise that was developed to advance the understanding of short-term memory beyond the model presented by chunking theory (Miller, 1956). Gobet developed a computational model of learning in chess called CHREST (chunk hierarchies and retrieval structures) to simulate patterns of memory encoding and retrieval (Gobet, 2001).
Temporal contiguity effect	"People learn more deeply from a multimedia message when corresponding animation and narration are presented simultaneously rather than successively" (Mayer 2005, p. 183).

Thayer method	Also called flipped learning or flipped classroom, the Thayer method (Shell, 2002) reverses the traditional teaching pattern by expecting learners to do self-guided pre-learning in anticipation of coming to classes, which focus on the application of knowledge in a supported and interactive environment. The expectation of the Thayer method is that learners have an established base of prior knowledge in the particular knowledge domain.
Threshold concept	Threshold concepts (Meyer & Land, 2006) express the idea of troublesome knowledge (Perkins, 1999) within disciplines and how learners transition beyond their current state of knowledge into an understanding of new, frequently difficult disciplinary knowledge. Threshold concepts represent the key ideas that are required to be understood within disciplines. Meyer and Land (2003, p. 1) describe a threshold concept as the learner passing a stage where a new, transformational perspective or altered paradigm for the interpretation and understanding of something is gained.
Time–to–mastery	Time–to–mastery is a construct introduced in this study to indicate the personalisation of a learner's time frame for mastering a node of expertise. Bloom (1968) suggested that a systematic change to education is required to allow every learner to achieve mastery. (Reigeluth (1994, p. 3) observed: "Two things educators know for certain are that different children learn at different rates and different children have different learning needs, even from their first day at school. Yet our industrial-age system presents a fixed amount of content to a group of students in a fixed amount of time, so it is like a race in which we see who receives the As and who flunks out. Our current system is not designed for learning; it is designed for selection".
Traditional teaching/learning models	Defined in numerous ways; also called industrial age teaching/learning (Reigeluth, 1994, 1999; Watson & Reigeluth, 2008), where education is presented via:

	a. standardised, "one-size-fits-all" models that operate within a norm-referenced framework and provide low levels of time flexibility for learners to attain mastery of their knowledge domains b. models that are based on a range of expectations and assumptions that the presentation of knowledge will result in learning without specific personalisation of learning to the individual needs of learners. This is contrasted with information-age models that adopt an evidence-based, learner-centred paradigm of education within a criterion-referenced learning framework that considers the needs and aspirations of learners as part of the learning process.
Triage	A medical term to describe "the process of quickly examining sick or injured people, for example after an accident or a battle, so that those who are in the most serious condition can be treated first" (www.collinsdictionary.com). In this study, triage aligns with the diagnostic processes that a teacher engages to determine the status of learning health of individual learners. The goal of this diagnostic process is to prescribe the most appropriate interventions to support the learner in advancing towards higher levels of expertise in knowledge domains as well as heutagogical capability.
Triangulation	Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena. Dick (1997, 2000a, 2000b) proposes that the purpose of triangulation is to either confirm or disconfirm findings as a stimulus to further research, not to prove that findings from each triangulation method are the same. Researchers can combine multiple data sources, observers, theories and method and can overcome issues raised by the use of singular methods or single-perspective theories and models.
Validation conversation (VC)	A Validation Conversation (VC) is the third part of a diagnostic and intervention cycle contributed through this study. After a node of expertise intervention has been set for a learner through a diagnostic conversation, the outcome of the implemented NOE intervention is reviewed by the teacher and learner within a VC in order to gauge the extent to which it has resulted in schema formation and automation. NOEs include discussions with individual learners regarding their

	motivation, interests and aspirations, levels of self-determined learning capability. CLEMS stores information arising from the DC-NOE-VC process for monitoring of the individual learner's progress towards higher levels of expertise.
Validity	Kelley (1927) is attributed with originating the concept of validity, which declares that a test is valid if it measures what it purports to measure.
Visible learning	Visible learning (Hattie, 2003; Hill, 2006; Ritchhart & Perkins, 2008) seeks to make unobservable cognitive processes that occur during learning more visible to teachers. In the context of CLT this involves identifying where learning experiences might be causing cognitive overload, or where the quality of the mental representations that learners engage to solve problems are erroneous or inadequately formed.
Visible thinking	Visible thinking (Bergeron, 2017; Collins, Brown & Hollun, 1991; Hattie, 2009, 2012; Ritchhart & Perkins, 2008) is related to visible learning, indicating the process of identifying the quality of the mental representations and processes of learners, with a view to identifying where these may be erroneously or inadequately formed (Church & Morrissey, 2011; Project Zero, 2016).
Waste in instructional design	The notion of waste in systems is a concept that has arisen from the lean process (Deming, 1986). Within learning design waste represents the recognition that learning may be ineffective due to lack of clarity by instructional designers and trainers as to the most efficient methods of presenting information for the purpose of developing expertise in learners (Clark, 2008a). The notion of waste in learning design is therefore an important, but under-researched factor in learning design. A tentative list of wastes in learning design derived from CLT research may include failure to consider the following: 1. prior knowledge of learners

	2. heutagogical capability of learners 3. the state and quality of schema development of learners 4. redundancy and split attention in learning materials 5. authentic learning contexts and fostering far transfer of knowledge.
Worked example effect	Worked examples, where problems are broken down into steps and each step is clearly explained, are designed to facilitate long-term memory schema formation and automation according to the information store principle. The worked example effect is evident when learners achieve better test outcomes from worked examples compared with a traditional problem solving approach (where learners are required to solve problems unaided by scaffolding or prompts) (Sweller, Ayres & Kalyuga, 2011). "The worked example effect is the best known and most widely studied of the cognitive load effects … the worked example effect throws light on the very foundations of human cognition" (Sweller, 2006b, p. 1).
Working memory	The part of the memory system in which schemas are consciously combined and integrated and in which new knowledge is constructed based on information entering through sensory memory (Velichovsky, 2017). Working memory is limited in storage capacity (Miller, 1956) and duration (Cowan, 2010, 2014) when dealing with novel information (Sweller, 1988) but despite these limitations, learning may be enhanced by engaging: a. long-term working memory b. the modality effect i.e. dual channels in working memory for processing visuospatial and auditory information c. the range of effects arising from CLT research for managing the loads in working memory in order to form and automate schemas (Sweller, Ayres & Kalyuga, 2011; Tindall-Ford, Agostinho & Sweller, 2020).

Zone of proximal development (ZPD)	Vygotsky (1930, p. 9) defined the ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers". The ZPD construct aligns conceptually with mediated learning (Dawes, 2006; Feuerstein, 2003), where the teacher or more knowledgeable other (MKO) represents an interpretive enabler between the learner's current level of knowledge and next higher level of knowledge. The gap between current knowledge and next-level knowledge state also aligns with liminal space (Meyer & Land, 2006).
xAPI	"The Experience API (or xAPI) is a new specification for learning technology that makes it possible to collect data about the wide range of experiences a person has (online and offline). This Application Program Interface (API) captures data in a consistent format [in a repository called a learning record store, or LRS] about a person or group's activities from many technologies. Very different systems are able to securely communicate by capturing and sharing this stream of activities using xAPI simple vocabulary" (https://xapi.com/overview).

Appendix B: Bloom's Mastery Learning Model Compared with Cognitive Load Theory

This appendix contains an overview of Bloom's (1968) model of mastery education, which provides a rationale for evidence-based instructional methods in education (Bloom, 1984). Moreover, Bloom's model of mastery learning aligns with key principles derived from the model of human cognitive architecture arising from CLT. In particular:

a. the key differences in cognitive processes engaged by novices and experts that require consideration in learning design

b. the CLT principle of *novice learners and the narrow limits of change* that requires the formation and automation of schemas to be facilitated within a highly flexible time framework due to the inherently slow rate of change with which long-term memory assimilates and integrates new learning into existing schemas.

Effectively, Bloom's model of mastery learning and Sweller's CLT are both underpinned by an expertise-based model of learning. Bloom's model of mastery learning, as well as his research team's model of educational objectives (Bloom, Engelhart, Furst, Hill & Krathwohl, 1956), was derived from school-based educational observations. It is not asserted that these models apply in every respect to higher education, but they deserve consideration to the extent that they share some commonalities. In particular, learners engaged in undergraduate programs or courses are in a transitionary process between school-level learning which may be lower on the scale of learning objetives (e.g. knowledge, comprehension and application) and more complex learning associated with higher education (analysis, synthesis and evaluation). In terms of CLT, undergraduate learnes may engage in disciplines in which they are novices with low levels of expertise.

While Bloom (Bloom et al., 1956) led the team that formulated the development of the influential and ubiquitous taxonomy of educational objectives, he also advocated a pedagogical methodology for achieving learning objectives. This methodology espoused a paradigm shift away from norm-referenced, time-stressed educational practice towards mastery learning within flexible time frameworks. In other words, Bloom strongly suggested a personalised view of education that varied time-to-mastery for each learner without lowering the expectations of attainment for learners.

Underpinning this philosophy was Bloom’s critique of the faulty causal association between learner aptitude and subsequent learner achievement which asserts that “high levels of achievement are possible only for the most able students” (Bloom, 1968, p. 2). In contrast to this view of aptitude, Bloom concurred with Carrol’s view that aptitude is only a reflection of the time needed by learners to achieve mastery of specific learning goals (Carrol, 1963). Bloom was therefore highly critical of norm-referenced educational systems that reduced education to a competitive practice with varying standards for different learners, rather than providing the conditions within educational environments for varying time-to-mastery for each learner and providing adequate resources for the vast majority (95%) of students to achieve two standard deviations above the norm (Bloom, 1984).

The implications of Bloom's assertions regarding educational practice are radical in terms of teaching practice and profound in terms of their potential impact on raising Australia’s standard of education in the global arena. The practicalities of offering time flexibility to every learner while simultaneously retaining mastery learning as a goal are likely to remain a challenge in the foreseeable future; however, as Bloom was one of the key thought leaders and research contributors of the 20th century in terms of evidence-based teaching practices, his model of mastery learning deserves continued consideration. The specific strategies arising from CLT research form a natural extension to Bloom’s theoretical perspective, providing a suite of evidence-based pedagogical strategies for engaging all learners in formal learning environments on an expertise learning pathway.

The overarching principle which Bloom applies to his model of mastery learning is that at each end of the spectrum of learners, between one per cent and five per cent of learners will demonstrate especially high or low levels of capability. As a result, “the grade of A as an index of mastery of a subject can, under appropriate conditions, be achieved by up to 95% of the students in a class” (Bloom, 1968, p. 3).

The following points highlight the five key principles and assertions of Bloom’s model of mastery learning.

1. Aptitude is an indicator of time required to attain mastery rather than an indicator of capability regarding complex learning.

2. The quality of instruction in terms of its individualisation and personalisation for each learner is a key determinant of learner mastery of a subject.

3. The capability of the learner to understand instructional requirements for tasks is a key to the learner’s progress; therefore, support in this area should be available at the time it is needed, both through tutorial and group support and varied pedagogical methods.

4. Perseverance, represented by the amount of time that the learner dedicates to engagement in the learning task, is a critical contributor to the outcome of task mastery; where learning methods are poorly aligned with the needs of the learner, unnecessary additional time will be imposed on the learner, eventually resulting in frustration and disengagement from learning. Learning materials that are aligned with the learner’s capability profile should be carefully designed to avoid frustration and disengagement; in terms of CLT, learning should not be used for imposing search-based learning strategies (means–ends analysis) on novice learners. Alternatively, learning should focus on mastery of domain-specific knowledge and tasks

through the appropriately selected and judiciously applied learning experiences that have been designed to advance the learner towards higher levels of expertise.

5. The time allowed for mastery of domain knowledge should be determined by the individual learner's aptitude, not a decision based on timetabling or other factors. Since aptitude is a reflection of the learner's time-to-mastery (see Time-to-mastery), learners who are not allowed this time will not develop the required levels of mastery. Bloom (1968, p. 7) elucidates this point by stating:

> it is not the sheer amount of time spent in learning [either in school or out of school] that accounts for the level of learning. We believe that each student should be allowed the time he needs to learn a subject. And, the time he needs to learn the subject is likely to be affected by the student's aptitudes, his verbal ability, the quality of instruction he receives in class, and the quality of the help he receives outside of class. The task of a strategy for mastery learning is to find ways of altering the time individual students need for learning as well as to find ways of providing whatever time is needed by each student. Thus, a strategy for mastery learning must find some way of solving the instructional problems as well as the school organizational problems.

Additional points and principles for consideration in developing a model and strategies for learning based on mastery include:

a. mastery learning requires consideration of the learner's prior knowledge and capabilities, as well as the structure of learning environments in terms of appropriately selected learning interventions and institutional learning delivery schedules

b. contributors to mastery learning include personal tutoring and learner control within learning environments

c. mastery learning requires specific curriculum design where levels of mastery or achievement criteria can be objectively measured; summative evaluation provides teachers with insight to the stage of mastery achieved by individual learners

d. achievement should be primarily non-competitive (not norm-referenced, but criterion-referenced), since competition may be destructive to learning and development; preferably, intrinsic motivation based on objectively-determined criteria should be fostered to bring all learners to a specific stage of mastery (cf. Reigeluth, 1994)

e. mastery learning has affective consequences for the learner. Bloom (1968, p. 11) asserts that when learners attain mastery and receive objective feedback (comparison to an objective curriculum) and subjective feedback (from school, self and society), internal changes occur within the learner's self-concept, intrinsic motivation and value to society, as well as the learner's connection to the subject, thus fostering motivation for continued study (cf. Martin, 2016; Martin & Evans, 2020)

f. mastery learning fosters lifelong learning. Bloom (1968, p. 11) stated that:

> one of the more positive aids to mental health is frequent and objective indications of self-development. Mastery learning can be one of the more powerful sources of mental health. We are convinced that many of the neurotic symptoms displayed by high school and college students are exacerbated by painful and frustrating experiences in school learning. If 90 percent of the students are given positive indications of adequacy in learning, one might expect such students to need less and less in the way of emotional therapy and psychological help. Contrariwise, frequent indications of failure and learning inadequacy must be accompanied by increased self-doubt on the art of the student and the search for reassurance and adequacy outside the school ... modern society requires continual learning throughout life. If the schools do not promote adequate learning and reassurance of progress, the student must come to reject learning – both in the school and later life. Mastery learning can ... develop a lifelong interest in learning. It is this continual learning which should be the major goal of the educational system.

Appendix C: Cognitive Theory of Multimedia Learning: Summary of Principles

Mayer (2005) provides a summary of the evidence-based research for multimedia arising from the model of human cognitive architecture posited by CLT. These pedagogical principles strengthen learning by their deliberate inclusion into learning design in order to manage cognitive loads in working memory, for the purpose of forming and automating long-term memory schemas (cf. Fletcher & Tobias, 2005).

In terms of this study, these principles form part of the dynamic knowledge database of CLEMS (see Chapter 7), with examples of their use for teachers to model in their own contexts. It is suggested through the findings of the study that these principles be introduced into programs and courses one at a time over frequent learning intervention iterations. The functionalities of CLEMS are used to:

a. set, monitor and track the implementation process

b. report the outcomes of the inclusion of these principles over CI iterations (see Continuous Improvement).

Table C.1 23 Principles of multimedia learning (Mayer, 2005)

Number	Principle	Definition
1	Multimedia principle	"The observation, extracted from numerous research findings, that people learn better from words and pictures presented together than from words presented alone" (Mayer, 2005, p. 130).
2	Expertise reversal effect	Learning design strategies that strengthen learning for novices may exert a negative effect on more expert learners.
3	Split-attention principle	Better learning is facilitated when media components such as words and graphics are spatially (spatial contiguity) and temporally integrated (temporal contiguity) rather than separately presented.
4	Modality principle	Graphics and audio narration provide a stronger learning effect than graphics and printed text.
5	Redundancy principle	Learning is strengthened by the same information not being presented in more than a single format. Where different formats are used, each format should not make sense without the other.
6	Segmenting principle	Learning is strengthened when materials are presented in learner-paced segments or subsections in contrast with whole units.
7	Pre-training principle	Learning is strengthened when learners are introduced to the main concepts and terminology prior to extended, formal learning events.
8	Coherence principle	Learning is strengthened when extraneous or redundant materials are excluded from learning design.

9	Signalling principle	Learning is strengthened when cues are added to learning designs that include markers indicating how the materials have been organised.
10	Spatial contiguity principle	see Split-attention effect
11	Temporal contiguity principle	see Split-attention effect
12	Personalisation principle	Learning is strengthened when multimedia presentations have a conversational rather than formal style.
13	Voice principle	Learning is strengthened when voices are standard rather than machine-generated.
14	Image principle	Learning is not necessarily strengthened when the speaker's image is on the screen.
15	Guided discovery principle	Learning is strengthened when guidance is included in multimedia-based learning environments.
16	Worked-out example principle	Learning is strengthened when worked examples support initial learning.
17	Collaboration principle	Learning can be strengthened by participating in collaborative learning events in online learning environments.
18	Self-explanation principle	Learning is strengthened by learners generating [high quality] self-explanations of the processes with which they are engaged during learning.
19	Animation principle	Learning is not necessarily strengthened through the use of animations compared with static graphic images.
20	Navigation principle	Learning is strengthened through the provision of navigational aids in multimedia environments.
21	Site map principle	Learning is strengthened through the provision of site maps that confirm the progress of the learner through the course.

22	Prior knowledge principle	The prior knowledge of the learner should be taken into account in learning design as it is the most significant factor with regard to the design of new learning experiences; this is due to long-term memory schemas being the repository of all the learner's prior knowledge.
23	Cognitive ageing principle	Learning design principles and strategies that serve to expand or increase efficiency in the use of working memory capacity exert a strengthening effect on older learners particularly.

Notes*:* This type of collation is useful from a pedagogical perspective as it contributes towards a coherent, organised body of knowledge associated with cognitive principles of multimedia learning, with a greater focus on practical implementation procedures as opposed to their theoretical justification. A key function of the software instrument developed in this study is to serve as a repository and catalogue of the body of knowledge arising from CLT and the cognitive theory of multimedia learning. This format enables greater access to the body of knowledge from a "single source of truth" in order to apply it systematically within educational environments.

Appendix D: Levels of Research Quality in Medical Research

In this study, principles adopted from evidence-based practice (EBP) in medicine have been used to support the development of evidence-based practice in education. This appendix elaborates on some of the key approaches to EBP in medicine, with particular reference to their usefulness for deriving evidence-based standards in education.

The Cochrane Collaboration (Higgins & Green, 2011) provides several levels of quality ratings for medical research. Cochrane (1979), after whom the standard is named, noted: "It is surely a great criticism of our profession that we have not organised a critical summary, by specialty or sub-specialty, adapted periodically, of all relevant randomised controlled trials". The levels in the Cochrane Collaboration research quality model are as follows, from the highest to the lowest level of quality:

Systematic reviews

1. Critically appraised topics (evidence syntheses and guidelines): highest level
2. Critically appraised individual articles (article synopses)
3. Randomised controlled trials (RCTs)
4. Cohort studies
5. Case controlled studies; case series/reports
6. Background information/expert opinion: lowest level

A definition of evidence-based medicine is the intersection between clinical judgement, relevant scientific evidence and patients' values and preferences while acknowledging criticism and mixed responses from within the medical profession, specifically:

> Criticism has ranged from evidence-based medicine being old hat to it being a dangerous innovation, perpetrated by the arrogant to serve cost cutters and suppress clinical freedom. As evidence-based medicine continues to evolve and adapt, now is a useful time to refine the discussion of what it is and what it is not. Evidence based medicine is the conscientious, explicit, and judicious

> use of current best evidence in making decisions about the care of individual patients (Sackett et al., 1996, p. 71).

Shah and Chung (2009) suggest an approach that aligns with the Cochrane model, with the following three factors combining to form a triarchic model of evidence-based medicine:

a. best available evidence

b. clinical acumen

c. patient values.

Expanding this model, The Centre for Evidence-Based Medicine (https://guides.himmelfarb.gwu.edu/ebm) provides a series of recommended diagnostic questions for modelling evidence-based practice, as follows:

1. ASK– Convert the need for information into a focused clinical question. Use the PICO framework, a guiding acronym for the following factors:

- **Population:** the patient or problem
- **Intervention**: what you plan to do such as a specific test, treatment or therapy.
- **Comparison:** alternative treatment or method
- **Outcome**: relevant outcomes of your intervention

(Note: Retrieved from www.lib.uts.edu.au/guides/nursing-midwifery-health/evidence-based-practice/pico-framework).

2. ACQUIRE – Track down the best evidence with which to answer that question.

3. APPRAISE – Critically appraise the evidence for its validity, impact and applicability.

4. APPLY – Integrate the evidence with your clinical expertise and your patient's characteristics and values.

5. ASSESS – Assess the results of your intervention.

Two cardinal rules of EBM

a. Not all evidence is created equal – A hierarchy of evidence guides clinical decision-making.

b. Evidence alone is never enough – Competent physicians balance risks and benefits of management strategies in the context of patient values and preferences.

The relevance of these models to education and to this study is that they serve as a model for informing the design of an evidence-based educational standard that can be used to filter the most appropriate research findings for the purposes of the study. Of note is the fact that evidence-based medicine is a continually developing model that always requires the interpretation of research by a medical practitioner with regard to the specific needs of individual patients even when advanced artificial intelligence technology is used for diagnosis (Husain, 2011; see also IBM Watson Project, 2017). This model therefore supports the development of increased evidence-based educational practice, where teachers are the practitioners who serve a mediatory role in interpreting evidence-based guidelines for diagnosing learners' barriers to learning as well as devising appropriate learning interventions to support learners in overcoming these identified barriers.

Appendix E: Summary of Identified Approaches to Design, Teaching, Learning and Evaluation

Table E1 in this appendix provides a review of different approaches to learning design, delivery and evaluation in educational literature in the form of a taxonomy using simple descriptive coding, which provides a summary of the topic in a word or short phrase (Miles, Huberman & Saldanha, 2014).

This table represents a basic taxonomical classification of key approaches to learning design, delivery and evaluation, ranging from theoretical models to the use of advanced technological systems. This collated list is not comprehensive, since there are multiple thousands of sub-approaches to education in the literature e.g. only four *resources* are listed, but a Google search for *teaching resources* brings up 700 million results. Some approaches have a single reference (e.g. tools, meta-analyses) to represent the category. Again, search engines such as Google call up several thousand or million examples of each approach. The current selection represents a classification of key approaches in use, with the aim of identifying approaches using the two key classification criteria of evidence-based approaches adopted for this study, which are based on an underpinning model of cognition and derived from RCTs.

These approaches have been identified through an ongoing search over the duration of this study and represent a proposed taxonomic model that may be refined or extended as part of a future research direction. Some of these classifications may overlap or be categorised using different criteria. However, the current classification serves the purposes of the study in addressing the research question. Tentative conclusions based on this taxonomy include the following:

a. the diversity of approaches to learning design, delivery and evaluation suggests that more research needs to be done in future to conduct a factor analysis or appropriate alternative analysis process on these approaches in order to remove duplication and to weight them in terms of their relevance. This process could contribute to the development of a more generally accepted, collated and validated body of knowledge with regard to learning design;

b. the observation of how few of these surveyed approaches have a direct and explicit link to an underpinning theoretical model of human cognitive architecture with regard to the functions and interrelationships of working memory and long-term memory, thereby omitting the opportunity for the triangulation of educational theories against educational practices, which could serve to highlight strengths and weaknesses in practices (Patton, 1999);

c. the identification of CLT as an evidence-based, theoretical model of human cognitive architecture that has been used to predict specific learning effects and ratify them through randomised controlled trial experiments. This collation of approaches supports the use of CLT as a learning design system that has a substantial theory-to-practice link, with a suite of pedagogical strategies that can be used as an evidence-based standard for the new instrument developed in this study.

Table E.1 Taxonomy of approaches to the design–teaching–learning–evaluation cycle

Notes: This taxonomical classification represents the design–teaching–learning–evaluation cycle or parts thereof as represented in the literature, with coding key for taxonomic categories. Singular and plural coding key tags are be used depending on the context of the identified approach.

CODING KEY	
1	Checklist
2	Construct
3	Effect
4	Framework
5	Guideline/s
6	Instrument
7	Meta-analyses
8	Matrix
9	Method
10	Model
11	Paradigm
12	Resource
13	Rubric
14	Standard
15	Strategy
16	System
17	Taxonomy
18	Theory
19	Tools

Table E.2 Approaches to the design–teaching–learning–evaluation cycle (or parts thereof)

Notes: This table lists approaches to the design–teaching–learning–evaluation cycle (or parts thereof) identified in the literature review with taxonomical coding in column 3. Some approaches could be classified under multiple codes; however, one main code is used per approach for the purposes of this study.

#	Title	Description	Code
1.	4C-ID model	Van Merriënboer, Jelsma and Paas (1992) posited 4C-ID, the four component instructional design model, which was later elaborated into the ten steps to complex learning model (Van Merriënboer & Kirschner, 2018). Both the 4C-ID and the ten steps approaches are based on CLT and elucidate processes that facilitate the acquisition of complex or high element interactivity skills. The 4C-ID and ten steps models therefore align with criterion-referenced and expertise-based teaching methodologies (van Merriënboer, Clark & de Croock, 2002; van Merriënboer & Kirschner, 2018).	**Model**
2.	5-stage model	A supported and scaffolded 5-stage model for the facilitation of learning in online learning environments (Salmon, 2004, n.d.) that references an expertise learning model. The five stages are: a. access and motivation b. online socialisation c. information exchange d. knowledge construction e. development	**Model**
3.	8LEM learning events model	This model mirrors constructive alignment process and is for facilitating technology enabled learning as well as a pedagogical model for learning resource exchange (Motton, 2017).	**Model**

4.	ADDIE Model	ADDIE is an acronym for: Analyse–Design–Develop–Implement–Evaluate model, which also has derivatives (Branson, Rayner, Cox, Furman, King & Hannum, 1975; Molenda, 2003). ADDIE represents a general, high-level model of learning design. However, the ADDIE model does not specify learning paradigms or specific learning strategies, but is limited to expressing a macro-level process for developing learning programs and interventions and may therefore be regarded as a high-level instructional design process guide (Molenda, 2003).	**Model**
5.	A Guide to Creating Learning Design for VET	No longer accessible. Retrieved from http://toolboxes.flexiblelearning.net.au/documents/docs/Learning_design_tool_VET.doc	**Tool**
6.	American Distance Education Consortium	The American Distance Education Consortium has undergone a name change to Online Learning Consortium. The American Distance Education Consortium publishes the Online Learning Journal (OLJ). As the Online Learning Journal is a peer reviewed publication, it includes scholarly articles that justify practice based on theoretical models of learning (Online Learning Consortium, 2018).	**Guideline/s**
7.	Andragogy	Andragogy (Knowles, 1975, 1984a, 1984b) focuses on pedagogical principles of adult learning and self-directed learning. Andragogy recognises the different conditions required for adults to succeed as learners and has generated heuristic guidelines and principles of adult learning. However, andragogy does not relate learning to a specific model of cognition nor the mechanisms underpinning cognition during learning.	**Model**
8.	ARCS Model	The ARCS model, described by Kelly	**Model**

		(www.arcsmodel.com, 2016) as a motivational model of learning, comprises four instructional design stages. • Attention • Relevance • Confidence • Satisfaction	
9.	Instructional Systems Design (ISD)	Instructional Systems Design represents a set of training methodologies developed for military applications (Clark, 2008a), but broadly applied in technical education. It has been criticised for being too focused on inputs to training vs. outputs, which are posited as the most important part of training (Zemke & Rossett, 2002). The Instructional Systems Design model consists of both a matrix and a method. The matrix represents content on one axis (facts, concepts, processes, procedures and principles) and performance on another axis (remember and apply) (Dick & Carey, 1996).	**Model**
10.	Avoidance vs. approach (attitudes to learning)	Gross (2006) contributes the concept of punishment avoidance as a motivation for learning. The opposite attitude of avoidance is approach, suggesting a positively open attitude by the learner to the possibilities of learning. Some alignment occurs between avoidance/approach and fixed/growth mindsets (Dweck1998). The affective nature of the avoidance/approach construct aligns with other heutagogical parameters (cf. Roth & Cohen, 1986–Avoidance and coping with stress).	**Model**
11.	Backward Design	Backward Design (Tyler, 1949; Wiggins and McTighe, 1998, 2008) suggests that the most	**Model**

		effective learning design is created from considering targeted learning goals or performances, and then deriving the curriculum and teaching methods to achieve these performances. This approach represents an outcomes-based model of learning design.	
12.	Behaviourism	Dominant educational paradigm during the late nineteenth century and early twentieth century (David, 2007; Ertmer & Newby, 1993;Graham, 2017; McLeod, 2017; Skinner, 1959; Watson, 1913). Based on a stimulus–response (input–output) process, with no acknowledgement of how cognitive processes and mechanisms are relevant to learning.	**Paradigm**
13.	Biggs' 3-P model	Biggs' 3-P model is a learner-centric, dynamically integrated educational model that takes the learner's prior knowledge and motivation into account for learning design (Biggs, 1987, 1989) in three steps: Presage, Process, Product.	**Model**
14.	Bloom's Taxonomy of Educational Objectives, Vol. 1. Cognitive Domain	A framework consisting of six objective levels, each one increasing in complexity: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. Later revised to express these six levels as: Remembering, Understanding, Applying, Analysing, Evaluating and Creating. Bloom's Taxonomy was modelled on biological taxonomies (Bloom et al., 1956, p.1) and "was conceived as a means of facilitating the exchange of test items among faculty at various universities in order to create banks of items, each measuring the same educational objectives" (Krathwohl, 2002, p. 212; Anderson and Krathwohl, 2001; Wilson, 2013).	**Taxonomy**
15.	Bloom's	The second stage of Bloom's Taxonomy, developed	**Taxonomy**

	Taxonomy of Educational Objectives, Vol. 2. Affective Domain	by Krathwohl, Bloom and Masia (1964), reflecting five characteristics of the affective domain, based on the incremental development of internalised values: • Receiving Phenomena: An awareness and willingness to listen, demonstrates attentiveness • Responds to Phenomena: Actively participates and attends to particular phenomena • Valuing: Attaches values to phenomena • Organization: Prioritises values • Internalises Values: Develops a system of values that serves to regulate their behaviour which has pervasiveness, consistency, predictability This model has been criticised (Morshead, 1965) for claiming integrative association between cognitive and affective domains, yet seeking to define them as disparate functions.	
16.	Bloom's Taxonomy of Educational Objectives, Vol. 3. Psychomotor	The third stage of Bloom's Taxonomy; however, not developed by Bloom, but by different researchers including: Dave (1970), Harrow (1972) and Simpson (1972), with each researcher structuring psychomotor skill development to include a different sequence of actions and principles (Performance Juxtaposition Site, 1995).	**Taxonomy**
17.	Bloom's Revised Taxonomy of Educational Objectives	In the revised version of the original Bloom's taxonomy, descriptors have been changed, with each level represented as: Remember, Understand, Apply, Analyze, Evaluate and Create (Anderson and Krathwohl, 2001; Krathwohl, 2002, p. 216). Bloom's taxonomy, while remaining a dominant resource for	**Taxonomy**

		learning design, was not directly derived from empirical research	
18.	Cafe Toolkit (Cognitive Assistance Factor Evaluation)	Cafe Toolkit is a (discontinued) website resource supporting teachers in identifying and implementing strategies based on CLT into learning environments (Cafe Toolkit, 2017).	**Tool**
19.	Candle Taxonomy	Candle taxonomy is an interoperability model that facilitates a cooperative resource sharing between universities (Cordis, 2017).	**Model**
20.	CASTE System	The CASTE System provides learners with a list of all topics in a course as well as possible pathways for progressing between topics. This model enables learners to exercise choices regarding progress from one topic to the next (Romiszowski, 1986).	**Model**
21.	Checklist for Strong E-Learning	Moore (2015) provides the Strong E-Learning checklist, containing a useful list of principles for reflection on pedagogical processes in use during course evaluation or course creation e.g. "the goal of the project is to change performance in a visible, measurable way vs. the goal of the project is to transfer information into people's brains" (see also Fors, n.d.–Checklist). This checklist does not include any reference to specific subjects, learner experience, nor the purpose of the learning. Moreover, it does not reference an objective standard for determining the definition of strong from a theoretical perspective. In other words, the list items are generic, decontextualised, depersonalised and are not grounded in a knowledge domain.	**Checklist**
22.	Chico - Rubric	The Chico (2017) Rubric for Online Instruction	**Rubric**

	for online instruction	contains six evaluation areas and three evaluation levels per criterion within each of the six rubrics (Baseline, Effective and Exemplary), one of which is Instructional Design and Delivery. Notably, Chico does not reference research on cognitive mechanisms during learning or a model of human cognitive architecture.	
23.	Chickering and Gamson – Seven Principles for Good Practice in Undergraduate Education	Chickering and Gamson's (1987) Principles of Good Practice provide guidelines, directives or heuristics that are based on research at undergraduate college level in face to face environments.	**Guidelines**
24.	Clark Training	Clark (2010) developed guidelines as well as a range of methods for applying evidence-based principles of learning design arising from CLT to specific learning environments. Clark is arguably the most prolific author of books on interpreting and applying the effects, principles and strategies arising from CLT into learning environments.	**Guidelines**
25.	Cognitive Apprenticeship	Cognitive Apprenticeship (Collins, Brown & Newman, 1987; Ghefaili, 2003) is a model that represents a synthesis between traditional schooling and an apprenticeship model of learning. Cognitive Apprenticeship theory emphasises the importance of expert thinking processes as part of learning and the need to make hidden learning processes visible to learners during learning (Grant, 1992; Hamlyn, 1990; Hattie, 2009; Ritchhart & Perkins, 2008). The Cognitive Apprenticeship model suggests that while schools teach "large bodies of conceptual and factual knowledge, standard pedagogical practices render	**Model**

		key aspects of expertise invisible to students. It asserts that “too little attention is paid to the reasoning and strategies that experts employ when they acquire knowledge or put it to work to solve complex or real-life tasks" (Collins, Brown & Newman, 1987, p. 1). With a focus on applied learning strategies, the Cognitive Apprenticeship framework does not model learning with reference to the specific mechanisms of human cognitive architecture related to working memory and long-term memory (Collins, Brown & Holum, 1991).	
26.	Cognitivism	The dominant educational paradigm that arose historically after behaviourism (Neisser, 1967). Cognitivism interpreted learning in terms of its hidden cognitive processes and underpinning mechanisms e.g. the functions and interrelationships of working memory and long-term memory systems.	**Paradigm**
27.	Cognitive Load Theory	CLT (Sweller, 1988) views learning from the perspective of a unified model of human cognitive architecture (de Jong, 2010; Sweller, 1988, 1999). Sweller, van Merriënboer and Paas (1998, p. 251) stated that "Cognitive load theory has been designed to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance". CLT fulfills the requirements of a theory to a greater degree than other identified approaches as it explains learning in terms of the functions and interrelationships of working memory and long-term memory. CLT adopts other research findings that are also theoretically rationalised by being derived from known functions of human cognitive architecture e.g. Long-Term	**Theory**

		Working Memory (Ericsson & Kintsch, 1995) and the Self-Explanation Effect (Chi, 2000).	
28.	Cognitive Theory of Multimedia Learning (see Appendix C)	Richard E. Mayer (2005) extended CLT into the Cognitive Theory of Multimedia Learning (CTML) where the principles governing and guiding the application of CLT in multimedia environments have been elaborated and established. His collated work in this area has been published in sources including the Cambridge Handbook of Multimedia Learning (2005). Some of the principles and effects of cognitive theory of multimedia learning overlap with the definitions from CLT due to their specific applications in multimedia environments and are underpinned by assumptins of CTML. Appendix C provides a summary of the key principles collated by Mayer (2005, pp. 6–8) for guiding the design of Multimedia Learning (Mayer & Moreno, 2003).	**Theory**
29.	COI Model Community of Enquiry	"The Community of Inquiry theoretical framework represents a process of creating a deep and meaningful (collaborative-constructivist) learning experience through the development of three interdependent elements - social, cognitive and teaching presence". Retrieved from https://coi.athabascau.ca/coi-model/	**Model**
30.	Competency-based Education	Competency-based education (CBE) is a mastery-based educational model where time is regarded as flexible and norm-referenced teaching is rejected in favour of criterion-referenced teaching (Voorhees & Bedard-Voorhees, 2017). CBE is traditionally associated with vocational and technical education and is the underpinning model used in the TAFE (Technical and Further Education) system in	**Paradigm**

		Australia. Many universities in Australia also offer vocational courses and Australia has a system where both vocational education and higher education have been hybridised into a single framework (AQF - Australian Qualifications Framework) comprising ten achievement levels, with certificates, diplomas and advanced diplomas at the lower end of the scale and degrees and higher degrees at the higher end of the scale (see Vocational Education and Training).	
31.	Component Display Theory	Instructional design guidelines (Merrill, 1983) Retrieved from www.nwlink.com/~donclark/hrd/learning/id/component_display.html Merrill's (1983, 1994) Component Display Theory (CDT), which uses the two dimensions of content and performance to classify learning. Notably, CDT does not reference the specific underpinning cognitive mechanisms engaged during learning.	**Model**
32.	Constructive Alignment	Constructive Alignment (Biggs & Tang, 2011; Smith, 2008) is a model that represents a systematic, full-cycle approach to learning design that is organised around the principle of beginning with the design of the outcome of learning, then aligning content and pedagogy in order to achieve the outcome. This aligns with Wiggins and McTighe's (1998) model of "backward design" which specifies the same reverse design process.	**Model**
33.	Constructionism	Constructionism (Papert & Harel, 1991) extends the Constructivist paradigm into a more compete pedagogical model by encouraging learners to construct external artefacts to represent their inner mental constructions or representations. While	**Model**

		providing a focus on constructed artefacts that serve as evidence of eLearning, Wood, Smith and Grossniklaus (2001) observe that "Constructionists believe that knowledge is constructed and learning occurs when children create products or artefacts. They assert that learners are more likely to be engaged in learning when these artifacts are personally relevant and meaningful". This approach has some alignment with the Cognitive Apprenticeship model (Collins, 1991).	
34.	Constructivism	The dominant educational paradigm and philosophy that rose to dominance after Cognitivism, represented as a family of approaches that focus on learners as constructors of their own knowledge, with an emphasis on social learning environments (Glasersfeld, 2014; Matthews, 2002; Perkins, 1999).	**Paradigm**
35.	Content-Performance Matrix	The Content Performance Matrix is based on Merrill's (1983) Component Display Theory and is: a. aligned with the original Component Display Theory b. classifies learning along two axes: Types of content and Levels of performance. The Content Performance Matrix is also aligned with Instructional Systems Design (ISD) Clark (2008a, p. 50).	**Matrix**
36.	Connectivism	An emerging educational paradigm and theory that focuses on connections between learners within technology–enabled learning environments (Downes, 2012; Frosch-Wilke, 2016; Fuchs, 2010). Connectivism has generated debate regarding its role as a separate learning theory (Kop & Hill, 2008).	**Paradigm**

37.	Continuous Improvement (CI)	The construct of Continuous Improvement (CI) represents: a. ongoing validation or evidence-based approaches to teaching, learning and evaluation; and b. ongoing validation of improved learning outcomes for learners. The goal of CI is generally accepted as the advancement of learners towards higher levels of expertise in specific knowledge domains. CI is associated with Lean Six Sigma (Deming, 1986; Netland & Powell, 2016; O'Reilly, Healy, Murphy & O'Dubhghaill, 2017) and waste reduction in manufacturing processes; its principles have recently been introduced to process improvement in education (Francis, 2014; Yorkstone, 2016) At a deeper level, the notion of CI is implicit to all teaching (Masters, 2012).	**Construct**
38.	Debattista's (2018) comprehensive rubric	Debattista's (2018) comprehensive rubric for instructional design in eLearning provides a range of parameters for developing eLearning interventions, using a rubric based on fourteen pedagogical dimensions for evaluating eLearning.	**Rubric**
39.	Decoding the Disciplines	Decoding the Disciplines (Middendorf and Pace, 2004) is an expertise model used in some higher education environments that is positioned within a cognitive paradigm. The key premise is to foster expertise in specific disciplines, rather than attempt to teach generic critical thinking skills. In this respect, this model is aligned with CLT, which focuses on the domain-specificity of expertise. CLT in turn was based on the research into chess expertise by de Groot (1965) whose research findings concluded that expertise consisted of a massive	**Model**

		internalised bank of formed and automated schemas within a particular knowledge domain. Decoding the Disciplines outlines a 7-Step model for supporting students in overcoming barriers to progress in their learning. A key step is the deconstruction and articulation of processes used by experts for the purpose of teaching learners how experts think, process and approach problems i.e. for learners to understand "Disciplinary ways of thinking". Pace and Middendorf (2004) have collated pedagogical examples of this model that have been successfully used in diverse disciplines including Genetics, Molecular Biology, Astronomy, Humanities and History.	
40.	Developing an instrument for evaluating the quality of elearning design in Nursing education	This is a Master's thesis with literature review pertinent to this study due to the development of an evaluation instrument (Zhang, 2008). This instrument is presented in a text-based format with a focus on the knowledge domain of nursing (see also Nursing and Midwifery Board of Australia, 2017).	**Instrument**
41.	DialogPlus Toolkit	Dialog Plus Toolkit (2019) is an attempt to represent and support the decisions involved in the learning design process. It is currently inaccessible at referenced site: http://www.nettle.coton.ac.uk/toolkit	**Tool**
42.	Dreyfus & Dreyfus Model of Expertise	The Dreyfus and Dreyfus (1980) model is a five-stage process that emphasises progressively staged skill acquisition within knowledge domains as the goal of learning. This model delineates five steps of progression in the learner's journey from novice to expert. This has made it useful for pedagogical applications and has been extended into use in specific learning domains. An example of this is	**Model**

		Benner's (1982) novice–to–expert model, a learner-centric model of clinical competence for nurses. The Dreyfus and Dreyfus model is significant to CLT, which centres on the individual learner's advancement towards higher levels of expertise through schema automation. The Dreyfus and Dreyfus model delineates a pedagogical, 'how-to' process for defining the steps towards expertise, which aligns with increasing levels of schema formation and automation. This study has contributed an adapted Dreyfus and Dreyfus model as a resource to support teachers in diagnosing learning levels of knowledge and heutagogical capability (see Appendix A) at a detailed level that takes both domain knowledge and heutagogical (see Heutagogy) factors into account.	
43.	ECB Check	The ECB Check by Global Campus 21 (2018) "provides a set of quality criteria to assess eLearning program design, development, management, delivery and evaluation, as well as the quality of learning materials, methodology, media, technology and e-tutoring" (Food and Agriculture Organization (2011) Trust Fund Project, 2011, p. 14). These quality criteria also provide generic, decontextualised principles and online tools, but omit reference to specific knowledge domains and the unique challenges that learners might encounter in mastering domain knowledge.	**Checklist**
44.	EFQL	The European Foundation for Quality in e-Learning (2015) is a collaborative forum that has included a project called ECB Check model, which is a quality evaluation framework. A key function of ECB Check is its "focusing on quality improvement and	**Model**

		innovation for e-learning programs in capacity building. Providing international benchmarks, it will dramatically enhance the efficiency and effectiveness of capacity building processes which are using partly or fully technology-enhanced learning" (ECB Check, p. 11)(Butler, 2011; European Union, 2015; European Union, 2014; Organisation for Economic Co-operation and Development Report, 2008; Organisation for Economic Co-operation and Development Report, 2008, 2013; Tudevdagva, Hardt & Evgeny, 2013).	
45.	Effects	Effects are a special class of approach to the design–teaching–learning–evaluation cycle as they may represent psychological constructs to explain learning or represent teaching phenomena or strategies that have arisen from experiments, including randomised controlled experiments (RCTs). An early effect referenced in education was the Hawthorne Effect (Draper, 2018; French, 1953) which explained changes of behaviour in factory workers due to their knowledge of being observed. The Pygmalion effect (the name of which is derived from the Shaw play on which the musical theatre play of My Fair Lady was based) is a motivational theory which suggests that learners rise to the teacher's expectations of performance (Rosenthal & Jacobson, 1968). Effects arising from CLT differ in some key aspects from other approaches as they explain learning in terms of underpinning cognitive functions and mechanisms in two key areas: first, effects are based on a unified model of cognition that synthesises the findings arising from over one hundred years of cognitive research (see Chapter 4). Secondly, the effects arising from CLT give rise to pedagogical strategies that	**Effect**

		differentiate between novice and expert learners on the basis of prior knowledge levels (Sweller, 1988) and underpinning cognitive mechanisms (Sweller, 1999); specifically, the deliberate design of learning interventions to avoid of the default process of means–ends analysis for novice learners. The spectrum of effects represent a single category in this taxonomy.	
46.	Elaboration Theory	Elaboration Theory, which draws on cognitive learning theory (Wilson & Cole, 1992) was developed by Charles Reigeluth and his research cohort at Indiana University during the late 1970s (Reigeluth, 1995; Reigeluth, 1999, pp. 17, 94; Reigeluth, Beatty and Myers, 2017, pp. 2, 12, 16, 70-71; Reigeluth & Carr-Chellman, 2009, pp. 91–399). It is an instructional design theory that argues that content to be learned should be organised on a continuum from simple to complex order, while providing meaningful, authentic learning contexts in which new learning can be integrated. Elaboration Theory has attracted criticism for its lack of specificity in explaining the nature of authentic learning environments (Wilson & Cole, 1992). However, it has been modified in response to criticisms and emergent knowledge (Reigeluth, 1992). Elaboration theory does not link its assumptions to a predictive model of cognitive architecture, but aligns with CLT at a practical level through promoting the use of part–whole instructional strategies.	**Theory**
47.	Evaluating eLearning: A guide to the	Evaluating eLearning: A guide to the evaluation of eLearning (Attwell, 2006) falls into the sub-category of a specific project for a limited time duration, being	**Model**

	evaluation of eLearning.	a project that was funded for five years to investigate and report on factors that impact the quality of eLearning. This type of guideline, while useful, was not based on a sustainable strategy and therefore fell into disuse within the educational community. The referenced software instrument is not accessible online.	
48.	E-Learning Maturity Model	The E-Learning maturity model is defined as a "framework for guiding adoption of e-learning and improving the processes surrounding it to ensure improvements in student learning outcomes" (Marshall, 2013; Marshall & Mitchell, 2002; Marshall & Rossman, 2011).	**Model**
49.	E-Learning Framework	The E-Learning Framework (ELF) initiative is a collaborative framework developed by the U.K.s Joint Information Systems Committee (JISC), Australia's Department of Education, Science and Training (DEST), and the Carnegie Mellon Learning Services Architecture Lab (LSAL). The goal of the E-Learning Framework (ELF) initiative is to build a common approach to Service Oriented Architectures for education, as expressed in the LADIE reference model guides (E-Learning Framework, 2012).	**Framework**
50.	E-Learning Methodologies: a guide for designing and developing eLearning courses	This initiative was published by the Food and Agriculture Organization of the United Nations (2011) and is a research project initiative that provides guidelines for instructional designers and educators to inform the design of eLearning; however, the	**Guideline/s**
51.	Expertise Model of Learning	The Dreyfus & Dreyfus (1980) model provides a continuum consisting of five stages of expertise development: Novice, Advanced Beginner,	**Model**

		Competent, Proficient and Expert. As a model of expertise, it aligns with key areas of expertise research by interpreting the learner's advancement towards higher levels of expertise in a useful format for use by educators and learning designers (Chi, 2006a, 2006b; de Groot, 1965; Gobet, 2005, 2013, 2016; Kalyuga, Chandler & Sweller, 1998). However, the Dreyfus and Dreyfus model does not account for the expertise reversal effect (see Expertise Reversal Effect) (Kalyuga, 2007; Kalyuga, Ayres, Chandler & Sweller, 2003).	
52.	Fixed and Growth Mindsets	Dweck (2006) advances the constructs of fixed and growth mindsets of the learner, which are attitudes to learning that impact motivation, self-regulation and achievement (see Heutagogy) (Heckhausen and Dweck, 1998).	**Construct**
53.	Flexible Learning Network Australia	A consortium providing a framework called The Practical Guide to eLearning. The site is no longer accessible but is included in the event that it might become active again.	**Framework**
54.	Flipped Classroom	Lenn (2017) states that the United States Army's West Point Military Academy was initiated in 1804 to train military civil engineers. Under the direction of Colonel Sylvanus Thayer, who was superintendent from 1817–33, West Point Military Academy developed an instructional model (see Thayer Method) that later became known as the flipped classroom method. The model had the following characteristics:	**Model**

		• Students are provided with detailed learning objectives and a readable text at the start of a course • Performance objectives are clearly stated for each lesson • Progress is periodically verified through quizzes and reviews • Individual attention is provided to all students • Students are grouped in classes by ability. The University of Adelaide website provides an elaborated flipped classroom model based on a modified version of Bloom's Taxonomy (1956) as follows: "Carefully designed pre-class activities assist students to learn key concepts in a self-paced manner, developing their confidence and motivation to engage in peer-led discussions during class that lead to synthesis and application of these key concepts. Post-class assessment activities are clearly connected to pre-class and face-to-face class learning experiences and address 'capabilities that count,' making the students' learning relevant, real and sustainable". Retrieved from www.adelaide.edu.au/flipped-classroom/about	
55.	Frameworks (Taxonomic Category Descriptor)	Frameworks represent larger theoretical constructs that demonstrate the interrelationships between their components. In education, frameworks may reflect learning theories or hypothetical models for advancing the field of learning design. In addition, frameworks may represent technological architectures and systems for managing the design–teaching–learning–evaluation cycle, processing data and generating analytic reports. Frameworks	**Framework**

		represent complex, multi-faceted processes with interacting elements and components at multiple levels and are underpinned by assumptions regarding learning and learning management processes. The plethora of available educational frameworks demonstrates the need for clarification of learning and learning management processes; it also demonstrates the lack of a standardised approach to the design–teaching–learning–evaluation cycle. In terms of the goals of the study, since CLT is based on an expertise, mastery learning model of education, the use of a framework could provide a more transparent reflection of the progress of every learner against an incrementally structured scope and sequence within each knowledge domain.	
56.	Gagne's Conditions of Learning	Gagné's Conditions of Learning (Gagné, 1962, 1985, 1987; Gagné & Driscoll, 1968) describe strategies for different types of learning (verbal, intellectual, cognitive, attitudes and motor skills) in behaviouristic terms and suggests the triadic learner–stimulus–response process in learning (Aronson & Briggs, 1983; Botty & Shahrill, 2014).	**Model**
57.	Gagné's Learning Hierarchy	Gagné (1985) provided significant contributions to the understanding of instructional design by developing models of learning and a hierarchy of types of learning in order to inform the sequential arrangement of instructional design materials from simple to complex learning types. These models focus on detailed task analysis, statements of objectives in the form of behavioural outcomes, and principles for creating learning experiences in sequential order (Soulsby, 1975). Gagné described eight conditions of learning based on a performance	**Model**

		model, using behavioural as well as cognitive foci, as well as nine conditions (levels) of learning (Gagné, 1987; Gagné, Briggs & Wager, 1992; Gagné & Driscoll, 2000)(see Gagné's Conditions of Learning).	
58.	Goodyear's problem space of educational design	Goodyear advanced a model of educational design and networked learning "as a context in which to outline a novel approach to educational design" (Goodyear, 2005, p. 82), referencing Christopher Alexander's research on pattern languages (http://www.patternlanguage.com/). This novel approach forges a link between technicalities of design and the central place of values for the purpose of connecting educational design communities through encoding, sharing and using knowledge for educational design.	**Model**
59.	Guidelines for Good Practice	Guidelines for Good Practice: Effective Instructor–Student Contact in Distance Learning (Academic Senate for California Community Colleges, 1999) focuses on quality components of distance education, but does not reference an underpinning cognitive theory. A similar initiative has also been taken by the Quality Assurance Agency for Higher Education in the UK (2017) also provides supportive guidelines and resources for the development and delivery of eLearning.	**Guidelines**
60.	Hannafin and Peck Model	Hannafin and Peck (2011) present an Instructional Design Model that references the ADDIE model of instructional design (Molenda, 2003; Branson, Rayner, Cox, Furman, King & Hannum, 1975), with the addition of a cyclical process of continuous revision. This model may therefore be said to be a derivative of the ADDIE model (see ADDIE).	**Model**

61.	Holistic Conceptual Framework	Zaharias (2004) developed a holistic framework for evaluating E-Learning design quality which provides a learner-centered approach that includes affective, cognitive, social and collaborative factors. This framework also emphasises learning contexts, views learning as a process and factors in feedback, instructional assessment and use of multimedia.	**Framework**
62.	IDOL (Instructional Design Online)	Siragusa (2006) developed a model of learning design for his doctoral dissertation, in which he developed an instructional design model for higher education called IDOL (Instructional Design for Online Learning). IDOL uses a "slider" metaphor to represent twenty-four learning design evaluation parameters that users move to represent levels of particular parameters. The IDOL model has been conceptualised with a multimedia user interface design metaphor, but according to a recent search has not yet been developed into a software instrument.	**Model**
63.	IMS Learning Design	IMS (Information Management Systems) Global provides the Simple Sequencing standard, which defines and outlines a method for representing the intended behaviour or actions of a designed learning experience in order that any learning technology system (LTS) or learning management system (LMS) is able to sequence separate learning activities consistently (IMS Global Learning Consortium, 2020).	**Standard**
64.	The Institute of Electrical and Electronics Engineers	The Institute of Electrical and Electronics Engineers (IEEE) provide standards to support searching for content during the learning object creation phase of a learning activity or intervention, as well as for	**Standard**

	(IEEE)	describing and meta-tagging learning activities after the creation process when they are stored (Institute of Electrical and Electronics Engineers, 2018).	
65.	Information-age Construct of Teaching, Learning and Evaluation	The information-age construct of teaching and learning (Reigeluth, 1999) has emerged as a construct for a futuristic envisioning of learning in the digital age that incorporates technology enabled learning environments (TELEs) and harnesses recent and emergent technologies to support pedagogical goals. This construct acknowledges the use of digital technologies including database-driven learning management systems, personalised and adaptive learning (Reigeluth, 1995; Reigeluth, 1999, pp. 17, 94; Reigeluth, Beatty & Myers, 2017, pp. 2, 12, 16,70-71; Reigeluth & Carr-Chellman, 2009, pp. 91–99) and learning analytics (Larussen & White, 2014; Reeves & Reeves, 1997; Siemens, Dawson & Lynch, 2013; Thomas, Barab & Tuzun, 2009).	**Construct**
66.	Instrumental Enrichment	A cognitively-based system based on Piagetian learning theory for diagnosing and correcting cognitive dysfunctions related to learning. Instrumental Enrichment is based on the theory of Structural Cognitive Modifiability (SCM) posited by Feuerstein (Feuerstein, 2003; Feuerstein and Jensen, 1980). Instrumental Enrichment includes training programs for teachers to administer diagnostic tests to learners, followed using instruments (corrective learning resources) for intellectual growth in areas diagnosed as dysfunctional.	**Instrument**
67.	Interactive Learning	Interactive Learning Systems Evaluation is a model that was developed by Reeves and Hedberg (2003)	**Model**

	Systems Evaluation	based on three key principles: a. evaluation activities are a critical aspect of the effective development of interactive teaching and learning systems b. evaluation may frequently be neglected due to hurried agendas that drive the generation of products that need to be on time. c. evaluation should be a key factor that guides the creative development process of learning design by providing insightful, timely information about design ideas as well as the quality of their implementation.	
68.	Kolb Learning Cycle	The Kolb Learning Cycle (Kolb, 1984; Sims, 1983) is a holistic model of the learning process, represented as a multilinear model of adult development and has been derived from experiential learning theory which Kolb asserts has its roots in the work of Dewey, Lewin and Piaget, but is fundamentally different from rationalist, cognitivist and behavioural learning theoretical paradigms. Kolb (1984, p. 36) defined learning as "the process whereby knowledge is created through the transformation of experience".	**Model**
69.	LAMS (Learning Activity Management System)	Learning Activity Management System (2002–2020) is a development and delivery environment for setting up learning activity sequences. The system is equipped with capabilities for live monitoring and interaction.	**System**
70.	LASO Model	Uys (2007, 2015) developed the propositional LASO (Leadership, Academic & Student Ownership and Readiness) Model for the technological transformation of higher education at an enterprise-wide level. LASO represents a holistic model of organisational transformation with regard to	**Model**

		education. The goal of LASO is depicted as an integrated 3-stage transformation that occurs via; a. top-down b. bottom-up and c. inside-out transformational processes. LASO is notable as a theoretical construct that has been validated in practice through implementation in large educational institutions. The conclusion of the thesis (Chapter 11) provides a recommendation that the LASO model may be used as an organisational transformation framework for implementing CLEMS.	
71.	Learning Tools Interoperability	Learning Tools Interoperability (LTI), an initiative of the IMS Global Learning Consortium (2003), is a standard created designed to link digital learning content and resources to existing learning platforms. For example, it connects learning management systems (LMS) to external services in a standardised way across different learning systems. IMS Global Consortium provides specifications for Learning Design to define learning activities, participants and roles in learning environments, as well as content packaging both for offering learning content packages and for packaging learning content for sharing across systems (IMS Global Learning Consortium, 2020).	**Standard**
72.	Laurillard's Conversational Framework	Laurillard's conversational framework (Laurillard,1999, 2001) represents the learning process as a type of conversation between the teacher and the learner, or at a peer level between students and should function at the level of operations and actions in the context of the world. This model draws on Vygotsky and Piaget's social constructivist theories. It also references conversation theory (Pask, 1975, p. 1) which elaborated on "techniques designed	**Framework**

		to exteriorise cognitive operations, especially those of learning and of teaching, so that they can be observed as segments of dialogue and behaviour. One method of exteriorising cognition is to engage in a verbal conversation, with a learner for example, and to discuss the way he learns as he learns". Laurillard built on the conversational construct by asserting that complex learning involves: "a continuing iterative dialogue between teacher and student, which reveals the participants' conceptions and the variations between them, and these in turn will determine the focus for the further dialogue … there is no escape from the need for dialogue ... there is no room for mere telling, nor for practice without description, nor for experimentation without reflection, nor for student action without feedback (Laurillard, 2001, p. 71).	
73.	Learning-Centred Evaluation Framework	(Bain, 1999) provides an introduction to a special issue of the journal Higher Education Research and Development that focuses on learner-centred evaluation of innovation in higher education. This framework is relevant to the current study as it focuses on factors that impact quality of evaluations, providing "a showcase of evaluations in which prominence was given to evidence about the influence of the innovations on student learning". In particular, areas such as learning processes and meaningful evidence of student outcomes are given prominence (Higher Education Research and Development Society of Australia, 2017).	**Framework**
74.	LearnTechLib (Reference Database)	LearnTechLib (2020) is "a development of Global U Learning & Technology Innovation, a non-profit, 501(c)(3) organization. Sponsored by the Association	**Resource**

		for the Advancement of Computing in Education", it was formerly called EditLib. It contains over one hundred and sixty thousand peer-reviewed papers and is one of the database resources used for this study.	
75.	Learning Management Systems	Learning Management Systems are technological applications, frameworks or systems for creating, delivering, evaluating and administering learning and may be cloud-based or locally hosted by educational or other organisations. Some Learning Management Systems are based on underpinning theoretical models e.g. MOODLE is based on a constructivist learning paradigm (see MOODLE). However, the technologies on which Learning Management Systems are built show potential for advancing theoretical notions, models, constructs or paradigms. For example, Learning Management Systems are used to facilitate adaptive learning (Brusilovsky, 2003; Federico, 1999; Heusner, 2013; Kalyuga, 2009a; Lavieri, 2014), where learning interventions are dynamically adapted to meet the specific learning needs of individual learners. Learning Management Systems can also facilitate a personalised approach to learning (Bray & McClaskey, 2015; Institute for Teaching and Learning Innovation, 2015; McLoughlin & Lee, 2010), although the meaning of personalisation with regard to learning has varied interpretations within the literature and "the lack of a consistent definition and language for a relatively complex idea has hampered both understanding and effective implementation" (The Office of Educational Technology, 2017). The software that has been designed and developed in this study represents a new direction in Learning Management Systems, since it is specifically informed by CLT i.e. it	**System**

		facilitates the management of learning programs for cohorts and individuals on an expertise model of learning, with learning outcomes focused on to the formation and automation of schemas through the management of cognitive loads in working memory (see Nodes of Expertise).	
76.	Learning Environment, Learning Processes and Learning Outcomes (LEPO) Framework	The LEPO Framework (Philips, 2011) is a comprehensive, holistic learning and evaluation framework that factors in the following components as being relevant to learning: a university-wide educational framework, a focus on individual learning including interactions with others and construction of new knowledge, inclusion of authentic learning tasks and also including informal learning with specific instructions in learning how to learn. LEPO aligns with: the constructive alignment model, scaffolding; facilitation of learning and graduate attributes. LEPO also includes affective factors, focusing on overall student well-being (see also Phillips, 2011–Towards a university educational framework).	**Framework.**
77.	Learning Outcomes: Melbourne Centre for the Study of Higher Education:	Popenici and Millar (2015) authored the guide Writing Learning Outcomes: A Practical Guide for Academics. This presents a holistic approach to writing outcomes and "is designed to: provide an introduction to the main concepts related to learning outcomes and course design, such as aims, goals, taxonomies, learning objectives, learning outcomes and constructive alignment; provide a succinct presentation of the most commonly used taxonomies of learning and their use in writing learning outcomes; and provide a guide to designing learning outcomes that are aligned with course aims, able to	**Guideline/s**

		inform selection of content, development of teaching strategies, design and selection of teaching materials (and resources)" (Popenici & Millar, 2015, p. 2).	
78.	Linnaeus' Taxonomy	Originating in biology with Linnaeus (1763), taxonomies represent a systematic approach to organising information e.g. the Linnaean system of biological classification. The study of taxonomy is also a scientific discipline in its own right, for example, the analysis and comparison of taxonomies from different disciplines. For example, Bloom's Taxonomy of Educational Objectives (Bloom, et al., 1956) and later revised taxonomy (Anderson & Krathwohl, 2001) are based on the Linnaean taxonomic structure. Thomas (2004, p. 1) states that "A taxonomy is an orderly classification of a field of study (e.g. botany, animal kingdom, anthropology) according to the natural relationships within the field. Taxonomies allow different researchers to study and discuss the same field of study using shared terminology". This Appendix summarises the literature review findings as a taxonomy and is one of the contributions of this study.	**Taxonomy**
79.	Matrices (taxonomic category descriptor)	Matrices provide a structural representation of complex knowledge bases. For example, Guilford (1950, 1967, 1982, 1988) developed a three-dimensional matrix to classify and categorise the components that comprise intellect or intelligence in a comprehensive cognitive matrix called Structure of Intellect (SI). The individual components of intellect are classed as viewed operations (cognition, memory, divergent production, convergent production, evaluation), contents (visual, auditory, symbolic, semantic, behavioral), and products (units, classes,	**Taxonomy**

		relations, systems, transformations, and implications). Guilford's matrix provides a comprehensive view of intellectual structure that is aligned with the processes of learning design. Possible uses of this matrix include its use as a diagnostic tool to create interventions to strengthen deficits in the knowledge of learners, or be used for creating resources that focus on learning needs at a more detailed level.	
80.	Meta-analyses	In the literature of education, the construct of meta-analysis is a standard approach for identifying the most efficacious methods for the structuring of learning environments to reflect evidence-based practice. Effectively, meta-analysis encourages the systematic organisation and interrogation of evidence (Halcomb & Fernandez, 2015; Slavin, 1984). Meta-analyses can provide valuable insights into the most effective learning strategies (Bloom, 1968, 1984; Merrill, 1983) and has become a common practice in the analysis of large bodies of research that may not have previously been collated (Hattie, 2009). In this taxonomy meta-analyses are treated as a single category.	**Meta-analyses**
81.	Method (taxonomic category descriptor)	Methods are prescribed approaches that provide guidelines or principles for achieving specific learning outcomes in formal learning disciplines and may occur at a micro (procedural) level or macro (systemic) level. Methods usually have a prescriptive or ordered structure and are ubiquitous in teaching. For example, methods of musical instrument instruction by Czerny (1893a, 1893b) for piano and for guitar (Sor, 1832), represent two early methodological approaches to learning. In many	**Method**

		medical teaching institutions, problem-based learning (PBL) has been adopted as a standard method of instruction (Barral & Buck, 2014; Kemp, 2011; Okada, 2009; Savin-Baden, 2014). Other examples of methods include the Thayer method (Nwosisi, Ferreira, Rosenberg & Walsh, 2016)(see Thayer method) and decoding the disciplines (Middendorf & Pace, 2004)(see Decoding the disciplines).	
82.	Office for Learning and Teaching Report	Office for Learning and Teaching (Office for Learning and Teaching, 2014) is a category of reports which represent collaborative quality assurance projects for strengthening teaching and learning in higher education. The project is introduced as follows: "Australian higher education requires a relevant and feasible way to assure the validity, reliability and comparability of assessment outcomes and achievement standards in equivalent university programs, subjects/units of study across the nation. This project addresses the Tertiary Education Quality and Standards Agency (TEQSA) imperative to demonstrate sector-level, self-regulated, robust approaches for assuring quality and standards and highlights the role of peer review (Grierson, 2013; Tertiary Education Quality Standards Agency, 2013, 2015, 2016, 2018).	**Strategy**
83.	Quality Assurance Agency for Higher Education in the UK	Quality Assurance Agency for Higher Education in the UK (2017) provides guidelines for the evaluation of quality in higher education, stating that "We safeguard standards and improve the quality of UK higher education wherever it is delivered around the world. We check that students get the higher education they are entitled to expect" (https://www.devex.com/organizations/quality-	**Guideline/s**

		assurance-agency-for-higher-education-qaa-135857)	
84.	Padagogy Wheel	Carrington (2017) designed and developed the Padagogy Wheel, which is an application (app) reference chart, published in numerous languages, for informing pedagogical decisions regarding choices of applications for different stages of learning. The Padagogy Wheel has a pedagogical focus and is nested within the SAMR Model (Substitution, Augmentation, Modification and Redefinition)(Puentedura, 2017). The Padagogy Wheel is not yet peer reviewed in Educational journals, but its high level of international popularity as a teacher support aid suggests that its structure and use may be suitable as a topic of research.	**Model**
85.	Personalised Learning	Personalised learning is a construct that has gained considerable traction in research since the 1980s (Bloom, 1984; Bray & McClaskey, 2015; Department of Education and Training, 2005; Institute for Teaching and Learning Innovation, 2015; Keppell, 2014; McLoughlin & Lee, 2010), although a universally accepted definition of personalisation or personalised learning has not yet been generated (The Office of Educational Technology, 2017).	**Construct**
86.	Quality Assurance of e-Learning	The European Association for Quality Assurance in Higher Education (2010) published a report titled Quality Assurance of E-learning. Its foreword (p. 5) states: "Because internet-based learning is currently such a relevant topic, there is a dire need for the creation of a common language and guidelines amongst all QA agencies in order to proceed in a collectively positive direction in regards to developing a quality culture within the frame of E-	**Framework**

		learning further".	
87.	Quality Learning Design	Quality Learning Design is a framework for learning design derived from evidence-based literacy and numeracy practices published by the Northern Territory (Australia) Government. Retrieved in 2018, it is not longer accessible.	**Framework**
88.	Quality Matters (QM): A National Benchmark for Online Course Design	Quality Matters (2017) is a quality assurance system that has the goal of improving the quality of learning and certifying quality through a rigorous process of evaluation. Its website (qualitymatter.org) states: "With online learning, everyone has a goal. Learners need to improve and grow. You work to nurture them with well-conceived, well-designed, well-presented courses and programs. Our goal - as a non-profit, quality assurance organization - is to provide a system to help you deliver on that promise: with review, improvement and certification of quality".	**System**
89.	Quality Online Learning and Teaching (QOLT)	Quality Online Learning and Teaching (QOLT) by California State University (Christie, 2014) represents a process for use by educators to evaluate quality related to CSUs goals. This is an example of a locally applied rubric, as is Kansas State University's Rubric for Quality E-Learning (2018), which provides a resource for supporting evaluation of eLearning within the university.	**Rubric**
90.	Quality Guidelines for Technology-Assisted Distance Education	Quality Guidelines for Technology Assisted Distance Education (1999) is a Canadian research-based, comprehensive framework for evaluating the quality of distance learning. The guidelines consist of seven principles for good practice, as follows: 1. encourages contacts between students and faculty	**Framework**

	(QGTADE)	2. develops reciprocity and cooperation among students 3. uses active learning techniques 4. gives prompt feedback 5. emphasises time on task 6. communicates high expectations 7. respects diverse talents and ways of learning	
91.	Quality Scorecard	The Online Learning Consortium (2018) provides a benchmarked standard (Quality Scorecard) for measuring and improving quality across key institutional areas including learning design. One of the scorecards titled Quality Course Teaching and Instructional Practice contains one hundred and eight checklist items. While comprehensive, this suggests a time consuming process for educators which may be more useful if factor analysis was applied to these items to determine the most critical items. Notably, this checklist also omits reference to a theoretical model of learning to justify its choices of list criteria.	**Checklist**
92.	Reigeluth's Elaboration Theory	Reigeluth (1992) developed the elaboration theory, which is a simple–to–complex curriculum structure, with meaningful content that is conceptually linked.	**Theory**
93.	General Resources	General Resources include search databases and other sources of access to articles and publication that are useful for initiating searches for specific research information. Included examples are: • Google Scholar (scholar.google.com), which serves a general search purpose for identifying researchers, articles and books; • LearnTechLib (www.learntechnlib.org), which provides a more specific focus on educational research • ResearchGate (www.researchgate.net), which	**Resource**

		identifies source articles and research on key educational topics • University libraries (for example, www.adelaide.edu.au/library/) that provides both book and journal references • Portals of aggregated information for learning support such as JISC (https://www.jisc.ac.uk), a non-profit organisation dedicated to supporting higher education research	
94.	Reeves model of E-Learning evaluation	Reeves (1998) developed a framework for evaluating education in multimedia environments, called computer based education (CBE). The f ramework is holistic, referencing fourteen key pedagogical dimensions informing learning that are "based on some aspect of learning theory or learning concept, that can be used as criteria for evaluating different forms of CBE" (Reeves, 1998, p. 1). The fourteen pedagogical dimensions included are epistemology, pedagogical philosophy, underlying psychology, goal orientation, experiential value, teacher role, program flexibility, value of errors, motivation, accommodation of individual differences, learner control, user activity, cooperative learning, and cultural sensitivity. As a holistic framework, this model includes a breadth of evaluation parameters that takes theoretical, affective and relational factors into account in learning environments, therefore reflecting a, personalised learning approach.	**Framework**
95.	Reeves and Reeves model for interactive learning on the web	Reeves and Reeves (1997) put forward a model for interactive learning on the web. It was based on Carroll's (1963) model, which emphasises aptitude and time required for effective learning to occur (cf. Bloom, 1968). The model includes dimensions of:	**Model**

		a. opportunity to learn (time available to learn), b. ability to understand instruction, c. quality of instructional events, d. perseverance (the time student is willing to spend on learning tasks.	
96.	SAMR Model	Puentedura (2017) put forward a 4-stage model which is an incrementally adjusted continuum for progressing the adoption of technology in education to increasingly sophisticated levels, as follows: 1.Substitution, where technology serves as a substitute for traditional teaching 2. Augmentation, which also is a substitute for traditional teaching, but with some factor that augments the learner's experience 3. Modification, where the learner's task is significantly altered due to the use of technology, with is a transformative step 4. Redefinition, where technology enables a learner to have a learning experience that would not be possible without technology.	**Model**
97.	Learning by Doing Model	Schank (1995) developed a learning-by-doing model with the following principles: 1. Learning to do is prioritised over learning to know. 2. Goals should be meaningful, relevant, and of interest to the student. 3. Significant learning occurs when the subject matter is relevant to the aspirations and personal interests of the student. 4. Real-world contexts should be the basis of content knowledge. This model shares similarities with other personlised models, for example Alanazi (2016), Mayer (2014) and Papert and Harel (1991).	**Model**
98.	Sloan	The Sloan Consortium, now called the Online	**Checklist**

	Consortium Quality Scorecard Suite	Learning Consortium (Sloan Consortium, 2014) developed a portal that connects a community of practice in online learning. It offers conferences, training workshops and resources including the Quality Scorecard which the website (onlinelearningconsortium.org) describes as providing "institutions with the necessary criteria and benchmarking tools to ensure online learning excellence for the entire institution".	
99.	Blended Learning evaluation rubric (BLeR)	Smythe (2012) developed a framework for evaluating blended learning which provides a rubric for developing an eLearning evaluation framework. This useful tool requires considerable skill in devising evaluation frameworks and may be based on varied theoretical constructs.	**Framework**
100.	Social Learning Theory	Bandura (1997b, 2001) posited an integrative learning theory that included four required parameters of learning: observation, retention, reproduction and motivation. This approach does not have direct reference to an underpinning model of cognition.	**Theory**
101.	SOLO Taxonomy	The SOLO taxonomy, which stands for Structure of the Observed Learning Outcome, is a holistic means of classifying learning outcomes in terms of complexity levels, enabling assessment of the quality of work rather than an evaluation of individually scored items (Biggs, n.d.). Biggs and Collis (1982, p. 3) define the essence of the SOLO taxonomy as "concentrating on a common learning situation: one that involves the meaningful learning of existing knowledge...[the aim of the learner is] ... to learn some data, such as facts, skills, concepts, or problem-	**Taxonomy**

		solving strategies ... [then] ... to use those skills, facts or concepts in some way, such as explaining...solving a problem ... carrying out a task, or making a judgment".	
102.	Spiral Curriculum Theory	Bruner (1960) posited the Spiral Curriculum theory, which is based on the premise that "We begin with the hypothesis that any subject can be taught in some intellectually honest form to any child at any stage of development (1960, p. 33). Bruner's Spiral Curriculum is arguably one of the most influential learning theories of the Twentieth Century (Bruner, 1960; Harden, 1999). While Bruner is arguably one the most influential educators of the twentieth century, his assertion regarding learning capability is not rationalised using an underpinning model of cognitive architecture.	**Theory**
103.	Stereotype Threat	Stereotype threat is a term that describes the susceptibility of learners to internalise and self-confirm negative opinions or characteristics about their own social group i.e. to conform to stereotypical opinions or stigmas regarding one's identified social group (Steele & Aronson, 1995). "The term, stereotype threat, was first used by Steele and Aronson (1995) who showed in several experiments that Black college freshmen and sophomores performed more poorly on standardized tests than White students when their race was emphasized. When race was not emphasized, however, Black students performed better and equivalently with White students. The results showed that performance in academic contexts can be harmed by the awareness that one's behaviour might be viewed through the lens of racial stereotypes" (McInerny & McInerny, 2002, pp. 375-378; Stroessner & Good, n.d.)(see	**Construct**

		Heutagogy). Stereotype threat is included as a construct for consideration in learning environments, with a proposed research direction of examining the relationship between cognitive load and stereotype threat.	
104.	Systems	Systems (demonstrate interrelationships between components of learning design and may vary in their use of technology. Technological architectures provide exceptional potential for advancing teaching and learning towards evidence-based practices through hypothesis testing, theory validation, providing rapid feedback to learners and collating data for the purpose of generating analytical reports for decision-making by educators and organisations. For example, MOODLE (Modular Object Oriented Dynamic Learning Environment, 2012) the Learning Management System developed in Australia by Martin Dougiamas, is based on a Constructivist paradigm, with numerous functionalities (wikis, forums, communications, peer-reviewed learning activities, etc.) for fostering online collaboration. Several approaches to teaching, learning and evaluation have been identified as systems. These include Quality Matters (2017), which is a quality system consisting of rubrics and standards, reflecting a more complex process for evaluating the quality of learning design. The information-age construct adopted in this study (Reigeluth, 1995; Reigeluth, 1999, p. 17, 94; Reigeluth, Beatty & Myers, 2017, pp. 2, 12, 16, 70–71; Reigeluth & Carr-Chellman, 2009, pp. 91–99) represents a systemic approach that has been identified as a useful placeholder for envisioning future technological architectures for teaching, learning and evaluation. This system, which	**System**

		also represents a technological framework, is reviewed in greater detail in a later section with relevance to this study (Akoka, Comyn-Wattiau, Prat & Storey, 2017; Bertalanffy, 1968).	
105.	Taxonomies (Category descriptor)	Taxonomies represent schemes for identifying, describing, classifying and ranking information. Part of the interpretation of the literature review in this study has been to structure approaches to the design–teaching–learning–evaluation cycle. While Bloom's Taxonomy is ubiquitous in terms of informing learning design (Crone-Todd & Pear, 2001), taxonomies of educational approaches, systems and paradigms are generally in a nascent state in terms of development in the literature. Possible (but untested) advantages of developing taxonomies of educational approaches include identifying commonalities between approaches, grouping similar approaches, conducting factor analyses to eliminate the duplication of research and ranking the relative quality levels of research in order to increase evidence-based approaches to the design–teaching–learning–evaluation cycle.	**Taxonomy**
106.	TEQSA	Tertiary Education Quality Standards Agency (2018) is an Australian standards regulator in higher education. TEQSA provides a federally regulated framework of obligatory standards that are typically prescriptive of outcomes, but not of pedagogical strategies required to achieve these outcomes.	**Standard**
107.	The Ultimate E-Learning Design and Development	The Ultimate E-Learning Design and Development Checklist (n.d.) provides a comprehensive list of evaluation components for eLearning design and development, but does not explicitly reference an	**Checklist**

	Checklist	underpinning theoretical model.	
108.	Teaching for Understanding	Reigeluth (1999) and Entwhistle (2009) present the construct of teaching for understanding, which supports university lecturers in facilitating deep learning in students that leads to conceptual understanding. Teaching for understanding is a personalised learning approach that seeks to validate the individual learner's conceptual understanding of domain knowledge (Wilson, 2018).	**Construct**
109.	Thayer Method	A historical method that has risen to prominence in recent decades in online learning is the "flipped classroom". This method originated as the Thayer method at Westpoint Military Academy (USA) in the early nineteenth century (Shell, 2002), but may have been in use prior to that date. The method involves providing learners with subject content knowledge that they must engage with prior to face-to-face classroom sessions. This method implies an expectation of self-directed learning by the learner as well as a change in the teacher's role as the source of all subject knowledge. Learners come to class prepared to engage in the application of the knowledge they have learned as "pre-learning" or "pre-training", characterised by active engagement with issues, challenges and problems in the subject domain rather than a passive exposure to the subject.	**Method**
110.	Threshold Concepts	Meyer and Land (2003) posited the construct of Threshold Concepts (TCs), which is used in contemporary higher education to represent learners passing through portals of understanding into previously challenging areas of learning. TCs align with Perkins' Troublesome Knowledge (Perkins,	**Construct**

		1999) and Sweller's (1999) rote learning vs. learning with understanding discussion (Entwhistle, 2009; Rakes, 2017; Sweller, 1988, 1999; Wiggins & McTighe, 1998) which examine the notion of why some learners reach a point of "troublesome knowledge" (Perkins, 2006), or "bottlenecks" (Middendorf & Pace, 2004) in their learning beyond which they are unable to progress. Cousin (2006) observed that the value of Threshold Concepts is their role in supporting curriculum development. However, while TCs have been influential in recent pedagogical literature, the theory does not explain the pedagogy in terms of a model of human cognitive architecture.	
111.	Troublesome Knowledge	While Perkins (1999) originated the concept of troublesome knowledge, Meyer and Land (2003, 2005) paired it with threshold concepts (TCs) to arrive at a useful construct for understanding how learners emerge from areas of difficulty in order to progress to new levels of understanding. Troublesome knowledge expresses both the difficulty encountered by learners who struggle to progress beyond a certain barrier of understanding in their learning, as well the notion of learners needing to pass through a barrier (Bezzi & Happs, 1994), or bottleneck (Middendorf & Pace, 2004) to a new level of understanding where the troublesome knowledge is deeply learned to the point of being unforgettable.	**Construct**
112.	Vocational Education and Training	Vocational Education and Training (Australian Government Department of Education and Training, 2018) represents a federally regulated set of standards that are embedded in legislation, applying to all Registered Training Organisations in Australia.	**System**

		The website www.training.gov.au is the main government web portal for vocational education information and resources e.g. units of competency.	
113.	Visible Learning	A recent and significant meta-study related to effective teaching and learning has been conducted by Hattie (2009, 2012) who collated over twelve hundred separate studies to obtain a ranking of 252 factors that impact achievement in learning (Waack, 2018). Hattie's meta-analysis places learning strategies arising from cognitive research in three of the top ten factors that impact learner achievement: (1) cognitive task analysis; (2) Piagetian programs; and (3) strategy to integrate new learning with prior knowledge (Waack, 2018, p. 1). This finding supports the validity of research arising from Cognitivism to inform learning design.	**Meta-Analysis**
114.	(xAPI) Experience Application Programming Interface	xAPI (https://xapi.com/overview/) the experience API (Application Programming Interface) is a specification for an eLearning software system that integrates with other systems and devices to record and track a broad range of learning experiences, both formal and informal, in a framework called a Learning Record Store (LRS). An LRS may exist as a stand-alone system or within a learning management system. xAPI is regarded as the next generation of SCORM (Shareable Content Object Reference Model), a specification and standard for packaging and sharing learning content.	**Standard**

Appendix F: Diagnostic Tools for Teachers

This appendix provides further information and discussion regarding the rationale and purpose for developing specific tools that teachers may use to determine the level of prior knowledge and heutagogical capability of learners. These tools are derived from key concepts arising from CLT that are designed to advance the inclusion of CLT strategies into learning environments. In particular, the tools are built on the central premise of CLT that the individual learner's prior knowledge, as represented by formed and automated schemas, is the most significant factor impacting new learning. The pedagogical implication of this premise is that the more accurate the diagnosis of the learner's prior knowledge by the teacher, the more targeted the interventions can be interms of advancing learners to new levels of expertise. These diagnostic tools support the educational diagnostic process which shares similarities with the concepts and practices of triage and diagnostics that occur within evidence-based medical practice. This premise implies that educational practitioners require both diagnostic tools and a system for recording and monitoring the progress of learners as part of managing the state of their learning health (Saha & Dworkin, 2009) as well as overseeing and managing adaptive interventions.

Two tools for supporting teachers in diagnosing prior knowledge and heutagogical capability of learners have been diagrammed and described in Chapter 10.

An additional tool is proposed below:

Tool 1: The Fluency Plus/Minus One Model of schema automation

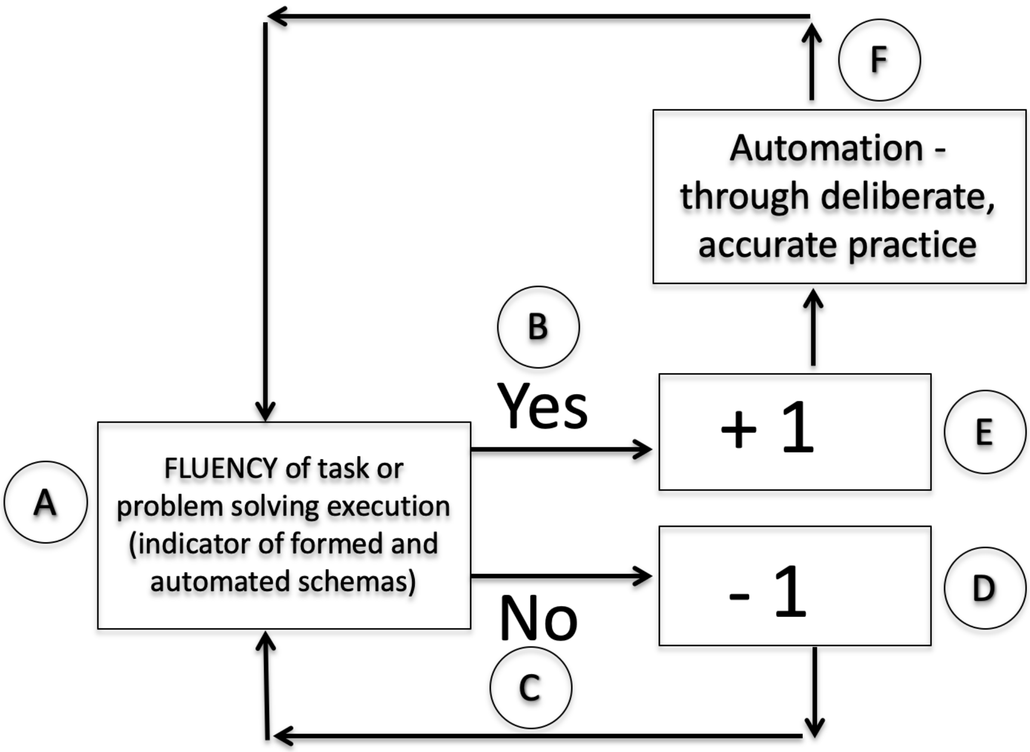


Figure F.1 A process map of the 'Fluency Plus/Minus One' Principle

Notes: This figure may be used for supporting teachers to find the highest level of expertise of novice learners i.e. identifying the highest level of schema formation as demonstrated by fluent execution of processes or problem-solving.

The process operates as follows for each circled stage of the process A-F above:

A: In any task, the teacher observes the level of fluency executed by the learner e.g. reading texts in a foreign language, doing a written task or solving a certain type of problem in physics.

B: If the teacher determined that the level of fluency is appropriate, a higher level of task is indicated i.e. introducing a new level of complexity to the task as indicated in the +1 stage (E). The learner then engages in deliberate, accurate practice at the new level of complexity until fluency is attained (F).

C: If the teacher determined that the level of fluency is not appropriate, a lower level of task is indicated i.e. introducing a lower level of complexity to the task as indicated in the -1 stage (D). In this case the learner is looped between stages D and A until the highest stage of fluent execution is demonstrated. As soon as this is identified, the teacher prescribes tasks with incrementally more complex chunks of information.

Notes: Fluency of execution of complex problem solving is taken to represent the cognitive state of automated schema development, where *complex* means high element interactivity in working memory involving prior knowledge interacting with new knowledge. This process is underpinned by the known limitations of working memory, as well as the narrow limits of change principle, which explains that long-term memory has unlimited storage capacity, but limited capacity for change. This model accounts for variations in working capacity since it first seeks the highest level of schema formation and uses this as the starting point for new learning. Examples: reading/playing a musical instrument/ballet. Furthermore, it affirms the mediative–adaptive role of the teacher for identifying and adapting four variables: the current level of schema formation of the learner, the granularity of new learning, the time over which new learning is introduced, and the curation of new learning until it has been automated into a schema.

Figure F1 is therefore a model to support teachers in designing learning interventions; the model focuses on automation (fluency of execution of skills in complex knowledge clusters, or NOEs) as an indicator of low cognitive load in working memory. This model implies that the learner's highest level of schema formation and automation needs to be identified as the starting point for new learning.

CLT assumes that evidence of learning is demonstrated through the formation and automation of accurate schemas; all the effects (or strategies) arising from CLT support the schema formation and automation process (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011) through the management of cognitive loads imposed on the working memory system during learning (see Cognitive Loads). From a pedagogical perspective, schema automation is represented by evidence of fluency of execution of problem-solving, or application of automated rules and principles to new situations by learners in near-transfer and far-transfer contexts (Sweller, 1988, 1999; Sweller, Ayres & Kalyuga, 2011).

The reason that automation occupies this key role in learning is that it represents the integration of multiple chunks of information into individual chunks (Sweller, 1988; Sweller, Ayres & Kalyuga, 2011), thereby freeing capacity for learning in working memory, which is limited in terms of processing capability (Cowan, 2010, 2014; Miller, 1956; Sweller, 1988) and duration of retention of information (Cowan, 2010; Peterson & Peterson, 1959). The implications for the design of learning environments and interventions are that they need to be organised to facilitate learners attaining accurate schema formation and automation, represented as acquiring expertise in specific knowledge domains (Chase & Simon, 1973; de Groot, 1965; Sweller, Ayres & Kalyuga, 2011); moreover, the pedagogical application of this process requires learning designers and educators to have:

a. an understanding of the functional model of human cognitive architecture during learning;

b. its governing principles and the strengths and weaknesses of working memory and long-term memory systems; and

c. the suite of evidence-based strategies arising from CLT research that serve to align new learning with the structure and functions of human cognitive architecture.

The formation and automation of schemas has a signification implication with regard to the time allocated for learners to attain high levels of fluency in a knowledge domain. Time flexibility is noted as a key factor when chunks of knowledge (whether segmented or whole) are being automated into the larger concept being learned, due to the narrow limits of change principle (Sweller, Ayres, Kalyuga, 2011, p. 40). For example, a learner being introduced to solving integral of differential equations in calculus may be taught the definitions and rules to the point of mastery before integrating them into an entire problem-solving sequence. Other CLT effects are specific strategies for the formation and automation of complex (see Element Interactivity; Complex Learning) knowledge schemas.

In addition to sufficient time being allocated for learners to form and automate schemas, persistent, variable practice needs to occur for each segmented chunk of knowledge until it is mastered (Ericsson, Krampe & Tesch-Romer, 1993). This point cannot be over-emphasised: learning needs to be curated by the teacher to the point of full schema automation in order for the resources of cognitive architecture to be harnessed, since automated schemas are a key method of bypassing the limitations of working memory (Ericsson & Kintsch, 1995). This implies that the learning process should not be truncated before deeply-linked learning has occurred.

The implication of this process for curriculum development is that the curriculum should be organised into incremental steps that are linked both logically and conceptually, not organised by covering pre-set volumes of learning per year or other time period in a norm-referenced paradigm. This means that learners of all levels of prior knowledge can connect with authentic learning from the starting position of their own highest level of fluency of knowledge execution and progress along a pathway to expertise that is transparent and can be monitored by the teacher.

Where collaborative learning occurs, the incremental arrangement of the curriculum serves as one type of foil to "social loafing", or lowered effort by individuals (Aggarwal & O'Brien, 2008) that can occur where novice learners engage in discovery or unguided learning (Sweller, Ayres & Kalyuga, 2011, p. 230). The precise implications of social loafing need to be evaluated through further research. However, where teachers rely on collaboration between learners as a teaching strategy, an awareness of this pattern and the provision of appropriate interventions can ensure that learners are engaging in the rigorous, time-intensive, persistent tasks associated with complex learning.

In summary, Figure F.1 requires that the curriculum be structured around domain expertise and the learning delivery timetable allows sufficient time for learners of all levels of prior knowledge to attain mastery - thus presenting an individualised and personalised model of learning. It is noted that this process may impact curriculum at a policy level, since it implies changes to curriculum design and delivery based on the expertise paradigm of learning posited by CLT. This model therefore also implies a personalised, mastery model learning for all learner.

The key implication of this model (Figure F1) is that where learners demonstrate fluency of execution in a knowledge domain, low cognitive load is indicated. Where fluency is observed, germane cognitive load may be increased incrementally (“Plus 1” means the addition of one chunk of knowledge at a time) until fluency of execution begins to slow down. Slowing of execution indicates increased processing, and therefore increased cognitive load. A method of increasing germane load is to introduce additional chunks of knowledge to the learner using the segmenting effect (Sweller, Ayres, Kaluga, 2011, p. 225) i.e. where large, high element interactivity concepts are broken down into smaller parts which are automated before being combined into larger schemas.

With this model, teaching begins with the teacher discovering the highest level of fluency demonstrated by the learner. The design of the curriculum as a seamlessly integrated, incremental progression of interlinked knowledge and concepts plays a key function in this process i.e. the learner’s actual level of expertise may be ascertained, then advanced to higher levels.

Appendix G: Research Directions in Cognitive Load Measurement

This appendix is excerpted from Zhang (2018) and provides an overview of the research endeavours towards the quantifiable measurement of the three cognitive loads. It includes discussion points regarding recent research into the measurement of cognitive loads and the significance of this research to the current study.

To this point, no definitive, objective measures of the three cognitive load constructs have been successfully developed and applied (Sweller, 2018, pp. 3–7) i.e. objective and quantitative unitary measures of *intrinsic*, *extraneous* and *germane* loads. The following summarised points reflect research directions towards the goals of both subjective and objective measurement.

Reflective comments by the researcher are included, as well as reference to a proposed research design for contributing to this field based on the use of calibrated response rates and a curriculum that designed in incremental steps that increase element activity for the learner.

1. In terms of subjective measurement of cognitive load, the Paas (Paas, 1992) scale is the most well used, as well as the most useable due to its low level of intrusiveness within learning environments (Sweller, 2018, p. 7; Yeung Lee, Pena & Ryde, 2000).

2. Secondary tasks also represent a key research direction in determining cognitive loads.

3. Physiological measures such as pupillary responses have been investigated as a method of measuring cognitive load (cf. Mitra, McNeal & Bondell, 2017).

4. Some positive advances have been made in terms of determining the relative measurements of different loads (Leppink, 2010).

5. Computational and machine learning models have been used to predict why strategies such as problem solving imposed excessive loads on working memory (Anderson & Gluck, 2001;

Gobet, 2000, 2005, 2013, Minsky, 1975). These models have been a catalyst for the design and development of intelligent tutoring systems (Ma, Adesope, Nesbit & Liu, 2014).

6. Factors during acquisition such as learning time as well as performance (Chandler & Sweller, 1991; cf. Clark, 2008a, 2008b; cf. Ericsson, Charness, Feltovich & Hoffman, 2006; cf. Paas, 1992).

7. The study of patterns of errors by learners has also contributed to the subjective measurement of cognitive load (Paas, 1992; Sweller, Ayres & Kalyuga, 2011; Zheng, 2018).

8. The measurement of rate through spectral analysis (Paas & van Merriënboer, 1994a) was a research direction that demonstrated less sensitivity than the Paas (1992) scale.

9. Subjective ratings of difficulty have also been investigated as a potential measure of subjective cognitive load (Marcus, Cooper & Sweller, 1996) by focusing on the measurement of element interactivity.

10. Variations in the location of cognitive load tests i.e. after the learner's initial engagement in tasks, or at the end of their engagement in tasks. These choices are noted to be by personal preference of the researchers (Ayres, 2018, p. 12; Schmeck, Opfermann, van Gog, Paas & Leutner, 2015).

11. Multiple collections of cognitive load demonstrated that a delayed, single rating of the learner's effort after testing was "higher than the average of ratings after each task (immediate)"(Ayres, 2018, p. 12).

12. Paas and van Merriënboer (1993) expanded the original Paas scale (Paas, 1992) by including both task performance and mental effort. This combination assumed that if two strategies produced comparable outcomes, the strategy that engaged lower levels of cognitive resources represented the most efficient one. A rule-of-thumb was generated from this research: "high instructional efficiency resulted from high task performance and low mental

effort, whereas low instructional efficiency resulted from low task performance and high mental effort" (Ayres, 2018, p. 13).

13. Test performance has not always been consistent with subjective measures, raising concerns for research and therefore ongoing research is required to clarify the reasons for these inconsistencies (Ayres, 2018, p.1).

14. No theoretically justified reason has been posited for self-rating cognitive load measures to be limited to specific learning domains. While a significant amount of cognitive load research has been conducted into STEM (science, technology, engineering and mathematics), this range has expanded to other subjects including music, law, teacher pre-service training and English literature (Ayres, 2018, pp. 14-15).

15. Dual task experiments have used a secondary task while learners are engaged in a primary task as a measure of cognitive load (Park & Brünken, 2014, 2018),. The supposition is that the variation in load for the primary task will impact the execution of the secondary task. Reaction times to auditory tones memorisation of double-digit numbers and changes in colour of presented materials have been used as secondary tasks (Brünken, Steinbacher, Plass & Leutner, 2002). Reaction times to secondary tasks showed that the best learning strategy generated the lowest working memory load. The use of rhythm as a secondary task to measure cognitive load (Park & Brünken, 2014) represents the use of psychomotor skills as a construct for cognitive load measurement.

16. In terms of physiological measures already discussed (see Point 3), a correlation between pupil dilation and cognitive load has been recorded (Debue & van de Leemput, 2014; Zheng & Cook, 2012), suggesting that further research in this direction could yield useful pedagogical guidelines.

17. Online technology has provided opportunities for new research directions in the measurement of physiological effects of cognitive load in real time (van Gog, Rikers & Ayres, 2008), termed *online* measurement. In contrast, *offline* (van Gog et al., 2008) measurement refers to subjective measures. Xie and Salvendy (2000) developed a scale for defining qualities of loads, including instantaneous peak, accumulated, average and overall, which subjective scales are unlikely to capture to this level of granularity. This detailed approach contributes a small, supporting point in the argument for the use of the ontology of Critical Realism used in this study. Critical Realism posits a reality that is multi-layered, or stratified (Bhaskar, 2008) as well as multi-mechanistic. This paradigm is useful as a framework for interpreting and explaining the highly complex and multi-layered emergent view of cognition posited by CLT, particularly with reference to the research direction of the measurement of cognitive loads (Archer, Bhaskar, Collier, Lawson & Norrie, 1998; Bhaskar, 2008; Fleetwood, 2013; Sayer, 1998).

18. Eye-tracking, or ocular motor measures, present another form of physiological measure of cognitive load, where longer fixations are posited as correlating to level of cognitive load; however, multiple measures using convergent measurement data are recommended for obtaining greater reliability of cognitive load measurement (Cook, Wei & Preziosi, 2018).

19. While physiological responses show promise for advancing the understanding of cognitive loads during learning in real time, research in this area is in a nascent state and requires ongoing development. The conclusion of this study (see Chapter 11) proposes an experimental research model in this area, where combinations of a broad range of measures are posited as a research direction.

20. Measuring different types of cognitive loads is an active research direction in CLT. Ayres and Paas (2012) have contributed continued understanding in support of the identification and measurement of intrinsic cognitive load.

21. The NASA-TLX (Task Load Index) attempted to correlate task demand, effort and navigational demands respectively to intrinsic, germane and extraneous loads. It was validated that high performance corresponded to low cognitive loads, but no congruency was found for matching the three criteria to specific loads. It is noted that the premise of this study is based on the validated relationship between high performance output and low cognitive load (see Chapter 6).

22. Numerous multi-scale measures of specific cognitive loads have been devised, resulting in both promising and controversial findings. For example, by using factor analysis, Yeung, Lee, Pena and Ryde (2000) conducted a study whose finding pointed to multiple measures being stronger predictors of cognitive load than single item measures.

23. Martin (2018) investigated the role of individual differences with regard to cognitive loads, the role of Intelligence Quotient in relation to cognitive loads and the need for cognitive loads to be monitored in in situ, realistic environments. Chapter 11 proposes the inclusion of the Paas Scale (Paas, 1992) into digital learning environments for learners to self-monitor their cognitive load during learning tasks and for this information to trigger appropriate resources or support.

The preceding summarised points illustrate the robust level of research being conducted into the measurement of cognitive loads, both through single and multi-item measures.

The implications for this study are in the development of the *node of expertise* process for designing learning interventions. Since cognitive loads cannot be measured objectively and individually according to the *intrinsic*, *extraneous* and *germane* load constructs, the automation of high element interactivity NOEs are used as an indicator of automated schemas (Sweller, Kalyuga, Ayres, 2011, p. 90).

Appendix H: Focus Group 1 Resources

THE UNIVERSITY of ADELAIDE

Participant Information Sheet (.pdf)

You are invited to participate in a research study investigating the quality of E-Learning design. By signing the consent form, you will be choosing to be involved in the study under the conditions described in this Participant Information Sheet. Should you change your mind, you may withdraw at any time by contacting the researcher. Your withdrawal from this study will not prejudice you in any way.

Participant Information Sheet

Evidence-based E-Learning Design

As a stakeholder in the E-Learning community of practice, you are invited to participate in a PhD research project. You may be from one of the following stakeholder groups: academic researchers, managers, instructional designers, trainers/teachers, learners/users of E-Learning for tertiary study purposes, or other stakeholders with experience and expertise in E-Learning.

The project aims to contribute towards raising the quality of E-Learning design by gathering information from stakeholders within the E-Learning community of practice which may include:

1. Analysing current e-learning research and practices according to your own knowledge and expertise.
2. Investigating current methods of e-learning design quality evaluation and their research background.
3. Discussing and providing feedback regarding a proposed instrument for the evaluation of E-learning design.

Participation in this research is by invitation to stakeholders in the E-learning community of practice who have an interest in discussing and debating key issues related to the quality of E-Learning design, with the aim of contributing to, confirming or raising standards of E-Learning design. Your time commitment will be discussed and agreed upon based on your availability prior to any involvement.

Your participation in this project will involve contributing your knowledge, expertise and experience of E-Learning to one or more focus groups and/or interviews, as well as stating some details of your training and experience.

During the focus groups and interviews you will be provided with background information regarding E-Learning design and expected to respond from your own knowledge, expertise and experience

Figure H.1 Participant information sheet

Notes: This form provided relevant information to potential focus group participants.

THE UNIVERSITY of ADELAIDE

ADVERTISING FOR PARTICIPANTS (.pdf)

1. Advertising Materials

Information to be included in advertising materials for recruiting participants:

Members of the e-learning community of practice (Researchers, Managers, Instructional Designers, Lecturers and Tertiary Students) are invited to participate in a PhD research project aimed at improving the quality of e-learning design. The University of Adelaide Ethics Approval Number for this research is H-2014-081.

The project aims to contribute towards raising the quality of e-learning design by developing a model for evaluating e-learning design and refining it within the e-learning community of practice. You will be asked to provide feedback on a model for an e-learning design evaluation tool, which will include:

- The theoretical framework for the model
- The characteristics of the model
- The measurement parameters of the model
- The applicability of the evaluation instrument to your e-learning context
- Critique of the Action Research methodology used

Participation in this research is by invitation to stakeholders in the e-learning community of practice who have an interest in addressing issues related to the quality of e-learning design, with the aim of contributing to raising standards of e-learning design.

Your participation in this project will involve contributing your knowledge, expertise and experience of e-learning to one or more focus groups and/or interviews, as well as some details including your training and experience.

During the focus groups and interviews you will be provided with background information regarding learning psychology and e-learning design. You will then be asked to critique a proposed model for an evaluation tool. Your responses will contribute to refining the proposed tool for the benefit of the e-learning community of practice.

You may be recorded using audio-recording equipment for later transcription.

Anonymity will be maintained throughout the study and you will not be named in the final thesis. You will be identified as an e-learning stakeholder from a particular group, e.g., Instructional Designer, Students, Trainer/Lecturer, Educator, Manager. The responses in the focus groups or interviews will be collected, collated and reviewed by the researcher, David Isaacson, as part of the research for his PhD thesis. You will need to declare your ability to use internet access devices safely and your ability to communicate at a sufficient level of English to participate in this research.

2. Social media sites/websites

The information in point 1. will be included in advertising on the internet using the website www.elearningdesignphd.com as well as social media sites such as Facebook.

3. Information website

A website www.elearningdesignphd.com has been set up to provide potential participants with above information and downloadable forms required for participation, as well as other supportive and relevant information for participants.

Figure H.2 Advertising materials information

Standard Consent Form (.pdf)

Human Research Ethics Committee (HREC)

CONSENT FORM

I have read the attached Information Sheet and agree to take part in the following research project:

Title:	*Evidence-based E-Learning Design*
Ethics Approval Number:	**H-2014-081**

I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

I have a sufficient level of English language proficiency to participate in this project.

Although I understand the purpose of the research project it has also been explained that involvement may not be of any benefit to me.

I understand that I will not receive any remuneration for participating in this project.

I have been informed that, while information gained during the study may be published, I will not be identified by name and my personal results will not be divulged.

I understand that I am free to withdraw from the project at any time.

I agree to the interview being audio recorded for transcription purposes: Yes ☐ No ☐

I agree to be quoted by name in the research: Yes ☐ No ☐

I am able to use internet access devices safely: Yes ☐ No ☐

I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ____________________ Signature: ______________________ Date: __________

Researcher/Witness to complete: (not required for forms returned electronically or by post)

I have described the nature of the research to (*print name of participant*) ________________

and in my opinion she/he understood the explanation.

Signature: __________________ Position: _______________________ Date: __________

Figure H.3 Standard consent form

THE UNIVERSITY of ADELAIDE

Complaints Procedure Document (.pdf)

The University of Adelaide
Human Research Ethics Committee (HREC)

This document is for people who are participants in a research project.

CONTACTS FOR INFORMATION ON PROJECT AND INDEPENDENT COMPLAINTS PROCEDURE

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

Project Title:	Evidence-based E-Learning Design
Approval Number:	**H-2014-081**

The Human Research Ethics Committee monitors all the research projects which it has approved. The committee considers it important that people participating in approved projects have an independent and confidential reporting mechanism which they can use if they have any worries or complaints about that research.

This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (see http://www.nhmrc.gov.au/publications/synopses/e72syn.htm)

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project co-ordinator or one of the project supervisors:

Name:	**David Isaacson**	**Dr Edward Palmer**	**08 / 8313 6036**
Phone:	**0404541650**	**Dr Cate Jerram**	**08 / 8313 4757**

2. If you wish to discuss with an independent person matters related to:
    - making a complaint, or
    - raising concerns on the conduct of the project, or
    - the University policy on research involving human participants, or
    - your rights as a participant,

    contact the Human Research Ethics Committee's Secretariat on Ph. (08) 8313 6028, Fax (08) 8313 7325 or by email to hrec@adelaide.edu.au.
    Ethics approval number: **H-2014-081**

Figure H.4 Complaints procedure for study participants

David Isaacson, PhD Research Focus Group, 14 July 2016, University of Adelaide.

Form 1 A

Your Role: Academic Manager Educator Instructional Designer Learner

Rate the importance of including these characteristics in the instrument.

#	Instrument Characteristic	Rate the importance of including this characteristic in the instrument	Comments/Considerations
1	The instrument should evaluate the extent to which the learning material links practice to a theoretical model	None Low Med High	
2	The instrument includes a Learner Profile (see Learner Profile **Form 1B**)	None Low Med High	
3	The instrument includes a Learning Program Profile analysis (See Learning Program Profile **Form 1C**)	None Low Med High	
4	The instrument enables the teacher to select specific Learning Program Parameters to evaluate (**Form 1C**)	None Low Med High	
5	After analysis **1B** (Learner) and **1C (**Learning Program**)**, the instrument provides suggested intervention strategies for strengthening learning	None Low Med High	
6	After determining the weaknesses of the learning program (**Form 1B** and **Form 1C** analysis), the instrument enables the teacher to record a description of intervention strategies for the learner	None Low Med High	
7	The instrument is sustainable through community ownership	None Low Med High	
8	The instrument is extensible (adaptable/modifiable to include new evaluation parameters)	None Low Med High	
9	The instrument is mediative-adaptive (administered by the teacher)	None Low Med High	
10	The instrument is database driven (stores all data for current/later analysis)	None Low Med High	
11	The instrument is rapidly deployed (fast analysis and feedback to inform choice of learning interventions, eg radio buttons/sliders to select parameters)	None Low Med High	
12	The instrument is cloud-based (universally available, scalable)	None Low Med High	
13	The instrument is developed in the form of an application (app) that is downloadable from Google and Apple Stores	None Low Med High	
14	The instrument stores personalised student information (identity, learning profile) for future use	None Low Med High	
15	The instrument provides visualised data output expressing strengths and weaknesses of the learning program	None Low Med High	
16	Textual report output is provided expressing strengths and weaknesses of the learning program (e.g "This learning program is strong/weak because....and may be strengthened by including....")	None Low Med High	
17	The instrument is experiment-based (Design Based Research Process)	None Low Med High	

18	The instrument protects the privacy of evaluated learners other sensitive information	None Low Med High	
19	The instrument is educative for users (provides users with theoretical basis and research evidence for intervention strategies)	None Low Med High	
20	The instrument takes useability and user experience into account with interface design (eg Clear navigation aids/wizard included)	None Low Med High	
21	Other	None Low Med High	

Form 1B: Learner Profile Parameters

<u>Your Role</u>: Academic Manager Educator Instructional Designer Learner

Rate the importance of including these learner evaluation parameters in the instrument

#	**Learner Profile Parameter**	**Rate the importance of including this parameter in the instrument**	**Comments/Considerations**
1	The learner profile should include the level of the learner's prior knowledge of the subject	None Low Med High	
2	The learner profile should include should evaluate the extent of learner's metacognitive skills (Reflective learning, ability to separate knowledge from concepts)	None Low Med High	
3	The instrument should evaluate the learner's Self Efficacy (general self-belief in ability to succeed)	None Low Med High	
4	The instrument should evaluate the learner's digital literacy self-efficacy (confidence in own ability to overcome technological barriers)	None Low Med High	
5	The instrument should evaluate the learner's time management self-efficacy (confidence in own ability to manage study schedule)	None Low Med High	
6	The instrument should evaluate the learner's motivation - Internal (Desire to engage in learning)	None Low Med High	
7	Motivation - External (Community/family pressure/encouragement)	None Low Med High	
8	The instrument should evaluate the time elapsed since the learner last engaged in formal learning	None Low Med High	
9	The instrument should evaluate the learner's Language proficiency in the language of instruction	None Low Med High	
10	The instrument should evaluate the learner's social learning self-efficacy (confidence in engaging/interacting with learning community ie peers, groups, teacher)	None Low Med High	
11	The instrument should evaluate the learner's personal perceived need for learning	None Low Med High	
12	The instrument should evaluate the learner's transfer need for learning material (near or far)	None Low Med High	

Form 1C: Learning Course/Program Profile Parameters

<u>Your Role</u>: Academic Manager Educator Instructional Designer Learner

Rate the importance of including these parameters in the instrument:

#	Learning Course/Program Profile Parameter	Rate the importance of including this parameter in the instrument	Comments/Considerations
1	The instrument should evaluate how learning activities are linked to prior knowledge	None Low Med High	
2	The instrument should evaluate if pre- and post-tests are included in learning activities	None Low Med High	
3	The instrument should evaluate if rapid evaluation techniques are included to test learner prior knowledge	None Low Med High	
4	The instrument should evaluate if learning objectives are included in the learning program	None Low Med High	
5	The instrument should evaluate if learning real work/life applications are included in learning materials (eg case studies)	None Low Med High	
6	The instrument should evaluate if learning structured for learner control (asynchronous multimedia, movies, audio, learning modules)	None Low Med High	
7	The instrument should evaluate if learning is designed to include social presence (collaboration, group work)	None Low Med High	
8	The instrument should evaluate if learning material is separated into schemas (internalised organisational principles and structures) and knowledge (factual information)	None Low Med High	
9	The instrument should evaluate if learning material is organised into higher-level chunks, categories, principles, concepts, linked information	None Low Med High	
10	The instrument should evaluate if learning concepts are validated before knowledge is taught (ie learners demonstrate conceptual understanding, internalisation of concepts and principles)	None Low Med High	
11	The instrument should evaluate if worked examples, faded examples and full examples are provided in learning material	None Low Med High	
12	The instrument should evaluate if self-talk is taught as a skill within the learning program	None Low Med High	
13	The instrument should evaluate if schema validation skills are taught (concept mapping, graphic representation of concepts, verbal explanations of processes by learners)	None Low Med High	
14	The instrument should evaluate if realistic work examples and problems are provided	None Low Med High	
15	The instrument should evaluate if the learner's imagination is engaged in learning	None Low Med High	

17	The instrument should evaluate if expert guidance is available during learning	None Low Med High	
18	The instrument should evaluate if flexible delivery time is available to support schema development (deep understanding of underlying structure of learning, flipped classroom, re-learning)	None Low Med High	
19	The instrument should evaluate if goal-free examples are provided as exercises	None Low Med High	
20	The instrument should evaluate if the split attention effect is reduced/eliminated (ie graphic and textual material in close proximity)	None Low Med High	
21	The instrument should evaluate if the redundancy effect is recognised (extraneous or irrelevant materials reduced/removed form program)	None Low Med High	
22	The instrument should evaluate if means-ends analysis is avoided as a learning strategy	None Low Med High	
23	The instrument should evaluate if unsupported learning is avoided	None Low Med High	
24	The instrument should evaluate if the modality effect is recognised and used	None Low Med High	
25	The instrument should evaluate if risk associated with learning	None Low Med High	

Figure H.5 Data-gathering instruments (1A, 1B and 1C) for Focus Group 1 participants

Participant rating of this Focus Group
Circle the appropriate number(Scale 1-5 (1=low, 5=high)

1	The purpose of the Focus Group was clearly explained	1 2 3 4 5
2	Housekeeping/safety/conditions were clearly explained	1 2 3 4 5
3	Ethics forms and right of participants were clearly explained	1 2 3 4 5
4	Form 1A was clear and easy to follow	1 2 3 4 5
5	Form 1B was clear and easy to follow	1 2 3 4 5
6	Form 1C was clear and easy to follow	1 2 3 4 5
7	I learned about Cognitive Load Theory from this Focus Group	1 2 3 4 5
8	I learned about technology in education from this Focus Group	1 2 3 4 5
9	If the instrument was ready today, it would be useful to me in my role as an educational practitioner:	
10	The Focus Group would have been better if...	

David Isaacson, PhD Focus Group Questionnaires July 15, 2016

Figure H.6 Post-focus group rating form for participants

Appendix I: Information Portal for the Study

This appendix contains a screen shot of the front page of the password-protected information portal set up at www.elearningdesignphd.com by the researcher as well as information for potential participants in the study. The portal served as a central repository for forms and resources used for the duration of the study.

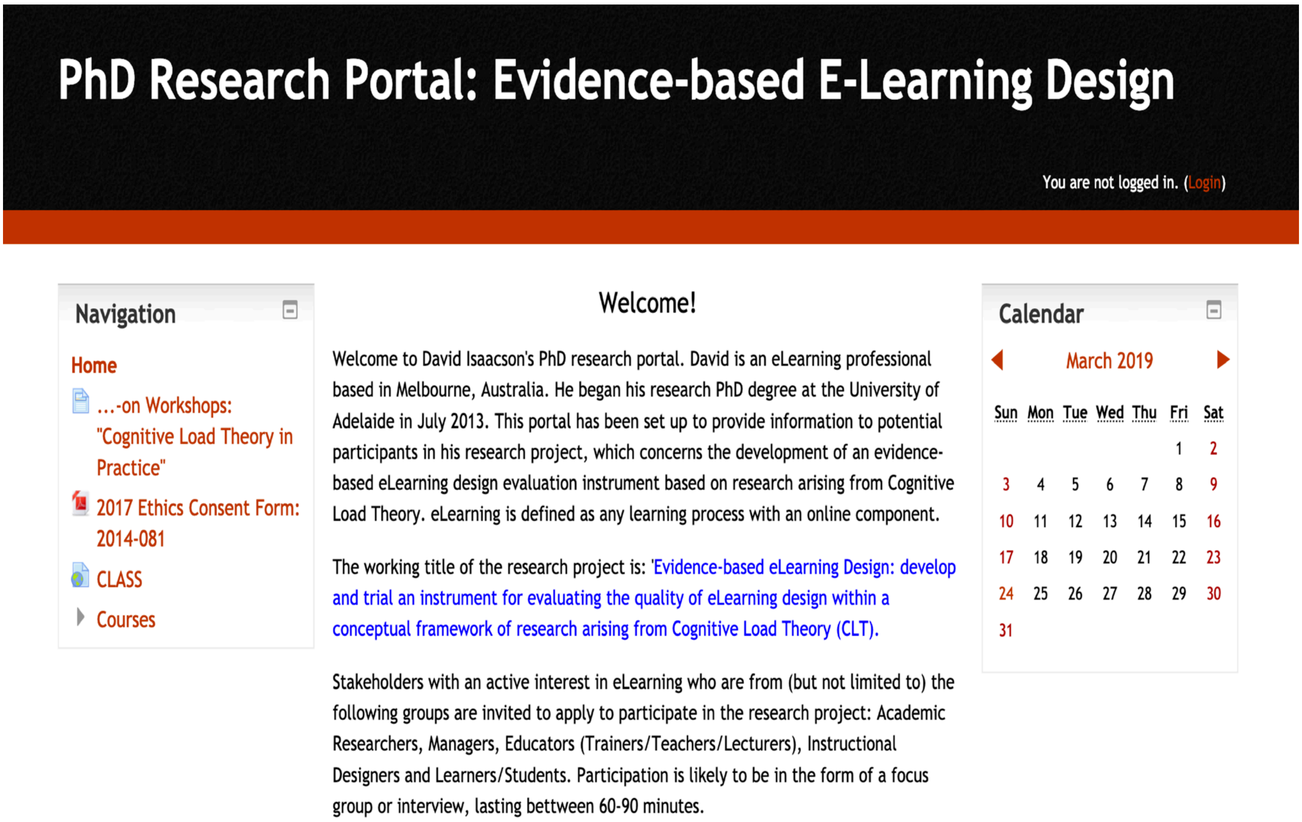


Figure I.1 MOODLE portal set up by the researcher at www.elearningdesignphd.com

Notes: This portal provided information to potential participants(see below) and served as a repository for key research forms and information for the duration of the study.

The following information was provided on the MOODLE portal represented in Figure I.1:

Welcome!

Welcome to David Isaacson's PhD research portal. David is an eLearning professional based in Melbourne, Australia. He began his research PhD degree at the University of Adelaide in July 2013. This portal has been set up to provide information to potential participants in his research project, which concerns the development of an evidence-based eLearning design evaluation instrument based on research arising from CLT. eLearning is defined as any learning process with an online component.

The working title of the research project is: "Evidence-based eLearning Design: develop and trial an instrument for evaluating the quality of E-Learning design within a conceptual framework of research arising from cognitive load theory".

Stakeholders with an active interest in eLearning who are from (but not limited to) the following groups are invited to apply to participate in the research project: Academic Researchers, Managers, Educators (Trainers/Teachers/Lecturers), Instructional Designers and Learners/Students. Participation is likely to be in the form of a focus group or interview, lasting between 60-90 minutes.

The main requirement for participating in this research project is an interest in contributing to the E-learning community of practice by providing feedback about the instrument through interviews or focus groups. The goal of the instrument is to provide eLearning stakeholders with information to make decisions that are better informed by evidence, with potential implications for learning design, learning outcomes and course production costs. The instrument is planned to be set up in an online, software environment.
The conceptual framework for this qualitative research project is based on CLT. A DBR methodology will be used to gather and refine the emerging findings through three iterative research cycles.

If you would like to be considered as a participant, please send an email to **info(at)elearningdesignphd.com**. **In the subject line, write: Request to participate in PhD research project.**

This portal contains the forms and necessary information that participants are required to complete prior to engaging in interviews or focus groups for this research project.

Note:

- If you are under 18 years old, you will be required to obtain written permission from a parent/guardian to participate in this project
- If you are not living in Australia, you will be required to verify in writing that you have permission to participate in this project and include written permission from your organisation or institution (where applicable)

Research is expected to begin in the second half of 2015. Please send an email to David at **info(at)elearningdesignphd.com** if you are interested in participating in this project.

The project will use a DBR methodology with three research iterations. Participants in the first iteration will be asked to answer questions that will guide the development of the instrument. Participants in the second iteration (who may be the same as the first iteration), will test the instrument on eLearning programs from their own practice or study, or to examples that have been provided, as well as provide feedback about the useability of the instrument. Participants in the final iteration will be asked to test the instrument on eLearning programs and provide feedback related to their own eLearning context.

This PhD will be submitted in the form of a thesis.

The privacy of participants is respected and access to the site is limited to the primary researcher and participants. Participants will only have access to areas relevant to their level of participation in the project.

The University of Adelaide Ethics Approval Number for this research project is H-2014-081.

[Hyperlinks to site areas]

How to Participate

Participant Information

Project Overview

Enter Participant Area

Link to Ethics Consent Form

In addition, the portal served as a repository for major and minor review documents, seminar and focus group presentations, ethics approval documents and other documents pertinent to the study.

Appendix J: Focus Group 2 Resources

THE UNIVERSITY of ADELAIDE

Participant Information Sheet (.pdf)

You are invited to participate in a research study investigating the quality of E-Learning design. By signing the consent form, you will be choosing to be involved in the study under the conditions described in this Participant Information Sheet. Should you change your mind, you may withdraw at any time by contacting the researcher. Your withdrawal from this study will not prejudice you in any way.

Participant Information Sheet

Evidence-based E-Learning Design

As a stakeholder in the E-Learning community of practice, you are invited to participate in a PhD research project. You may be from one of the following stakeholder groups: academic researchers, managers, instructional designers, trainers/teachers, learners/users of E-Learning for tertiary study purposes, or other stakeholders with experience and expertise in E-Learning.

The project aims to contribute towards raising the quality of E-Learning design by gathering information from stakeholders within the E-Learning community of practice which may include:

1. Analysing current e-learning research and practices according to your own knowledge and expertise.
2. Investigating current methods of e-learning design quality evaluation and their research background.
3. Discussing and providing feedback regarding a proposed instrument for the evaluation of E-learning design.

Participation in this research is by invitation to stakeholders in the E-learning community of practice who have an interest in discussing and debating key issues related to the quality of E-Learning design, with the aim of contributing to, confirming or raising standards of E-Learning design. Your time commitment will be discussed and agreed upon based on your availability prior to any involvement.

Your participation in this project will involve contributing your knowledge, expertise and experience of E-Learning to one or more focus groups and/or interviews, as well as stating some details of your training and experience.

During the focus groups and interviews you will be provided with background information regarding E-Learning design and expected to respond from your own knowledge, expertise and experience

Figure J.1 Participant information sheet for Focus Group 2

THE UNIVERSITY of ADELAIDE

ADVERTISING FOR PARTICIPANTS (.pdf)

1. Advertising Materials

Information to be included in advertising materials for recruiting participants:

Members of the e-learning community of practice (Researchers, Managers, Instructional Designers, Lecturers and Tertiary Students) are invited to participate in a PhD research project aimed at improving the quality of e-learning design. The University of Adelaide Ethics Approval Number for this research is H-2014-081.

The project aims to contribute towards raising the quality of e-learning design by developing a model for evaluating e-learning design and refining it within the e-learning community of practice. You will be asked to provide feedback on a model for an e-learning design evaluation tool, which will include:

- The theoretical framework for the model
- The characteristics of the model
- The measurement parameters of the model
- The applicability of the evaluation instrument to your e-learning context
- Critique of the Action Research methodology used

Participation in this research is by invitation to stakeholders in the e-learning community of practice who have an interest in addressing issues related to the quality of e-learning design, with the aim of contributing to raising standards of e-learning design.

Your participation in this project will involve contributing your knowledge, expertise and experience of e-learning to one or more focus groups and/or interviews, as well as some details including your training and experience.

During the focus groups and interviews you will be provided with background information regarding learning psychology and e-learning design. You will then be asked to critique a proposed model for an evaluation tool. Your responses will contribute to refining the proposed tool for the benefit of the e-learning community of practice.

You may be recorded using audio-recording equipment for later transcription.

Anonymity will be maintained throughout the study and you will not be named in the final thesis. You will be identified as an e-learning stakeholder from a particular group, e.g., Instructional Designer, Students, Trainer/Lecturer, Educator, Manager. The responses in the focus groups or interviews will be collected, collated and reviewed by the researcher, David Isaacson, as part of the research for his PhD thesis. You will need to declare your ability to use internet access devices safely and your ability to communicate at a sufficient level of English to participate in this research.

2. Social media sites/websites

The information in point 1. will be included in advertising on the internet using the website www.elearningdesignphd.com as well as social media sites such as Facebook.

3. Information website

A website www.elearningdesignphd.com has been set up to provide potential participants with above information and downloadable forms required for participation, as well as other supportive and relevant information for participants.

Figure J.2 Advertising materials information for Focus Group 2

THE UNIVERSITY of ADELAIDE

Complaints Procedure Document (.pdf)

The University of Adelaide
Human Research Ethics Committee (HREC)

This document is for people who are participants in a research project.

CONTACTS FOR INFORMATION ON PROJECT AND INDEPENDENT COMPLAINTS PROCEDURE

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

Project Title:	Evidence-based E-Learning Design
Approval Number:	**H-2014-081**

The Human Research Ethics Committee monitors all the research projects which it has approved. The committee considers it important that people participating in approved projects have an independent and confidential reporting mechanism which they can use if they have any worries or complaints about that research.

This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (see http://www.nhmrc.gov.au/publications/synopses/e72syn.htm)

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project co-ordinator or one of the project supervisors:

Name: **David Isaacson**		**Dr Edward Palmer**	**08 / 8313 6036**
Phone: **0404541650**		**Dr Cate Jerram**	**08 / 8313 4757**

2. If you wish to discuss with an independent person matters related to:
   - making a complaint, or
   - raising concerns on the conduct of the project, or
   - the University policy on research involving human participants, or
   - your rights as a participant,

   contact the Human Research Ethics Committee's Secretariat on Ph. (08) 8313 6028, Fax (08) 8313 7325 or by email to hrec@adelaide.edu.au.
   Ethics approval number: **H-2014-081**

Figure J.3 Complaints procedure for Focus Group 2 participants

THE UNIVERSITY of ADELAIDE

Standard Consent Form (.pdf)

Human Research Ethics Committee (HREC)

CONSENT FORM

I have read the attached Information Sheet and agree to take part in the following research project:

Title:	*Evidence-based E-Learning Design*
Ethics Approval Number:	**H-2014-081**

I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

I have a sufficient level of English language proficiency to participate in this project.

Although I understand the purpose of the research project it has also been explained that involvement may not be of any benefit to me.

I understand that I will not receive any remuneration for participating in this project.

I have been informed that, while information gained during the study may be published, I will not be identified by name and my personal results will not be divulged.

I understand that I am free to withdraw from the project at any time.

I agree to the interview being audio recorded for transcription purposes: Yes ☐ No ☐

I agree to be quoted by name in the research: Yes ☐ No ☐

I am able to use internet access devices safely: Yes ☐ No ☐

I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ____________________ Signature: ______________________ Date: __________

Researcher/Witness to complete: (not required for forms returned electronically or by post)

I have described the nature of the research to (*print name of participant*) ________________

and in my opinion she/he understood the explanation.

Signature: _________________ Position: _______________________ Date: __________

Figure J.4 Standard consent form for Focus Group 2

Appendix K: Focus Group 3 Resources

K.1 Human Research Ethics Committee - Research Approval

Human Research Ethics Committee (HREC)

THE UNIVERSITY *of* ADELAIDE

CONSENT FORM

I have read the attached Information Sheet and agree to take part in the following research project:

Title:	*Evidence-based E-learning design: The development and trialling of an E-Learning design evaluation instrument based on Cognitive Load Theory*
Ethics Approval Number:	H-2014-081

I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely.

I have been given the opportunity/now have the opportunity to have a member of my family or a friend present while the project was explained to me.

Although I understand the purpose of the research project it has also been explained that involvement may not be of any benefit to me.

I understand that I will not receive any remuneration for participating in this project.

I have been informed that, while information gained during the study may be published, I will not be identified by name and my personal results will not be divulged.

I understand that I am free to withdraw from the project at any time.

I agree to the interview being audio/video recorded for transcription purposes: Yes ☐ No ☐

I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ____________________ Signature: ______________________ Date: __________

Researcher/Witness to complete:

I have described the nature of the research to ______________________________________
(print name of participant)

and in my opinion she/he understood the explanation.

Signature: __________________ Position: ______________________ Date: __________

The University of Adelaide
Human Research Ethics Committee (HREC)

Figure K.1 Consent form for Focus Group 3

THE UNIVERSITY of ADELAIDE

ADVERTISING FOR PARTICIPANTS (.pdf)

1. Advertising Materials

Information to be included in advertising materials for recruiting participants:

Members of the e-learning community of practice (Researchers, Managers, Instructional Designers, Lecturers and Tertiary Students) are invited to participate in a PhD research project aimed at improving the quality of e-learning design. The University of Adelaide Ethics Approval Number for this research is H-2014-081.

The project aims to contribute towards raising the quality of e-learning design by developing a model for evaluating e-learning design and refining it within the e-learning community of practice. You will be asked to provide feedback on a model for an e-learning design evaluation tool, which will include:

- The theoretical framework for the model
- The characteristics of the model
- The measurement parameters of the model
- The applicability of the evaluation instrument to your e-learning context
- Critique of the Action Research methodology used

Participation in this research is by invitation to stakeholders in the e-learning community of practice who have an interest in addressing issues related to the quality of e-learning design, with the aim of contributing to raising standards of e-learning design.

Your participation in this project will involve contributing your knowledge, expertise and experience of e-learning to one or more focus groups and/or interviews, as well as some details including your training and experience.

During the focus groups and interviews you will be provided with background information regarding learning psychology and e-learning design. You will then be asked to critique a proposed model for an evaluation tool. Your responses will contribute to refining the proposed tool for the benefit of the e-learning community of practice.

You may be recorded using audio-recording equipment for later transcription.

Anonymity will be maintained throughout the study and you will not be named in the final thesis. You will be identified as an e-learning stakeholder from a particular group, e.g., Instructional Designer, Students, Trainer/Lecturer, Educator, Manager. The responses in the focus groups or interviews will be collected, collated and reviewed by the researcher, David Isaacson, as part of the research for his PhD thesis. You will need to declare your ability to use internet access devices safely and your ability to communicate at a sufficient level of English to participate in this research.

2. Social media sites/websites

The information in point 1. will be included in advertising on the internet using the website www.elearningdesignphd.com as well as social media sites such as Facebook.

3. Information website

A website www.elearningdesignphd.com has been set up to provide potential participants with above information and downloadable forms required for participation, as well as other supportive and relevant information for participants.

Figure K.2 Advertising materials information for Focus Group 3

This document is for people who are participants in a research project.

CONTACTS FOR INFORMATION ON PROJECT AND INDEPENDENT COMPLAINTS PROCEDURE

The following study has been reviewed and approved by the University of Adelaide Human Research Ethics Committee:

Project Title:	*Evidence-based E-learning design: The development and trialling of an E-Learning design evaluation instrument based on Cognitive Load Theory*
Approval Number:	H-2014-081

The Human Research Ethics Committee monitors all the research projects which it has approved. The committee considers it important that people participating in approved projects have an independent and confidential reporting mechanism which they can use if they have any worries or complaints about that research.

This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research (see http://www.nhmrc.gov.au/publications/synopses/e72syn.htm)

1. If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the project co-ordinator: or one of the project supervisors:

Name:	**David Isaacson**	**Dr Edward Palmer**	**08 / 8313 6036**
Phone:	**0404541650**	**Dr Cate Jerram**	**08 / 8313 4757**

2. If you wish to discuss with an independent person matters related to:
   - making a complaint, or
   - raising concerns on the conduct of the project, or
   - the University policy on research involving human participants, or
   - your rights as a participant,

   contact the Human Research Ethics Committee's Secretariat on phone (08) 8313 6028 or by email to hrec@adelaide.edu.au.

Figure K.3 Complaints procedure information for Focus Group 3 participants

Research Participant Information Sheet
November 2017
Trialling a Prototype Learning Design Evaluation Instrument

and/or interview.

THE UNIVERSITY of ADELAIDE

You are invited to take part in a research study investigating the quality of E-Learning design. **By signing the consent form, you will be choosing to be involved in the study under the conditions described in this Participant Information Sheet.** Should you change your mind, you may withdraw at any time by contacting the researcher and your withdrawal from this study will not prejudice you in any way.

Participant Information Sheet
Evidence-based E-Learning Design

As a stakeholder in the E-Learning community of practice, you are invited to participate in a PhD research project. You may be from one of the following stakeholder groups: academic researchers, managers, instructional designers, trainers/teachers, learners/users of E-Learning for tertiary study purposes, or other stakeholders with experience and expertise in e-learning.

The project aims to contribute towards raising the quality of E-Learning design by developing an E-Learning design software evaluation tool based on Cognitive Load Theory. E-Learning is defined as any learning experience that includes an online component.

Participation in this research is by invitation to stakeholders in the E-Learning community of practice who have an interest in discussing and debating key issues related to the quality of E-Learning design, with the aim of contributing to, confirming or raising standards of E-Learning design.

Your participation in this project includes contributing your knowledge, expertise and experience of E-Learning and/or learning theory to one or more focus groups, interviews, and software trials.

During the focus groups and interviews you will be provided with background information regarding E-Learning design and expected to respond from your own knowledge, expertise and experience as a stakeholder in the E-Learning community. You will be asked to provide feedback about the usefulness of the prototype instrument in your own educational context.

Anonymity will be maintained throughout the study and you will not be named in the final thesis unless you agree to this in writing. You will be identified as an E-Learning stakeholder from a particular group, e.g., Academic Researcher, Instructional Designer, Lecturer/Trainer, Educator, Manager, or Student. The responses in the focus groups or interviews will be collected, collated and reviewed by the researcher, David Isaacson, as part of the research for his PhD thesis.

Your privacy whilst participating in this study will be maintained at all times. You may withdraw from participation at any time without prejudice. You may choose to have a support person with you when conditions of participation are explained to you.

This study has been cleared in accordance with the ethical review processes of the University of Adelaide (Ref: H-2014-081). You are free to discuss your participation with project staff. If you would like to speak to an officer of the University not involved in the study, you may contact the Secretary, Human Research Ethics Committee, Research Ethics and Compliance Unit, Research Branch, Level 7, 115 Grenfell Street, The University of Adelaide SA 5005 Ph. (08) 8303 6028, Fax (08) 8303 7325, email sabine.schreiber@adelaide.edu.au

Thank you for participating in this study.
Yours sincerely,

David Isaacson

Primary Researcher (Adelaide)
David Isaacson

Figure K.4 General information for participants, Focus Group 3

Post-Focus Group Evaluation Form
7 November 2017

Trial a software learning design evaluation tool based on Cognitive Load Theory

Please rate each of the following items for the focus group	**Your Rating (1=Low, 5=High} Circle Applicable**
The focus group was well organised	1 2 3 4 5
The procedures of the focus group were clearly explained	1 2 3 4 5
My rights as a participant were explained to me e.g. my right to withdraw at any point without prejudice	1 2 3 4 5
Safety procedures (e.g. emergency evacuation) were explained to me	1 2 3 4 5
I understood what was expected of me through clear written and verbal instructions	1 2 3 4 5
Sufficient time was provided to review the instrument and provide feedback	1 2 3 4 5
I learned about Cognitive Load Theory	1 2 3 4 5
My knowledge of educational theory increased	1 2 3 4 5
I had the opportunity to contribute ideas and feedback verbally and/or in writing	1 2 3 4 5
The food and refreshments were appropriate for the event and catered for my needs	1 2 3 4 5
The technology was appropriate for trialling the software	1 2 3 4 5
Appropriate technical support was available during the focus group	

Any other comments? (e.g. what you liked or didn't like?)

____

____

____

Thank you for participating in this focus group.
David Isaacson, Nov. 7, 2017
PhD Student (Primary Researcher)

Figure K.5 Post-focus group feedback form

CLEMS operating instructions for Focus Group 3 evaluation

Focus Group 3 participants were provided with detailed operating instructions for accessing and using the prototype instrument for a. course evaluations and b. individual student evaluations..

Notes: The following 11 pages contain Figure K.6, the operating instructions for CLEMS provided to participants in Focus Group 3. In this focus group the instrument was called CLASS, which was later changed to CLEMS as a term of reference throughout the thesis (see Chapter 1).

Focus Group: Trial an E-Learning design evaluation instrument based on Cognitive Load Theory

Instructions: Part 1
GENERAL COURSE EVALUATION

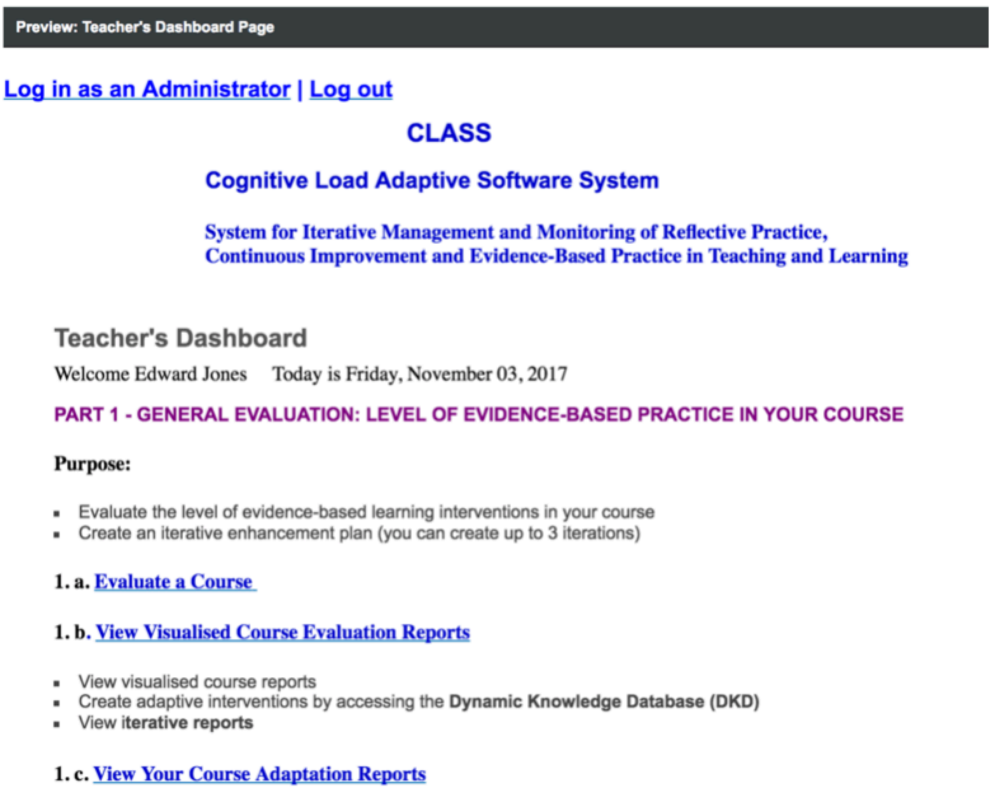
Aim: To evaluating and improve a course in 3 iterative cycles.

1. Click on the link that was emailed to you. This will take you to the **Teacher's Dashboard Page**.
Log in to the Teacher Dashboard:

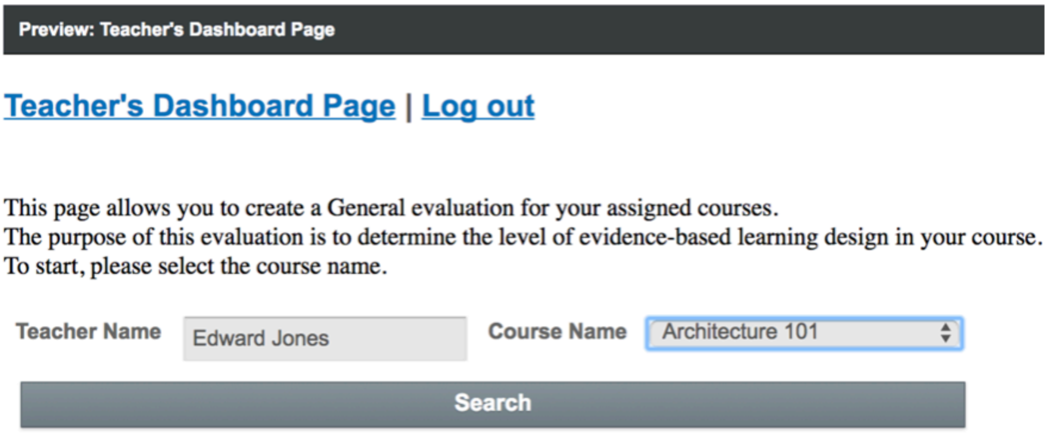
Requirements: Teacher login (your **email address** plus password: your **Firstname123&,** e.g. David123&)

Example:

2. This will take you to the **Teacher's Dashboard Page**, as follows:
This is part 1 (top section of the Teacher's Dashboard). You will use links **1.a.**, **1.b.**, and **1.c**.

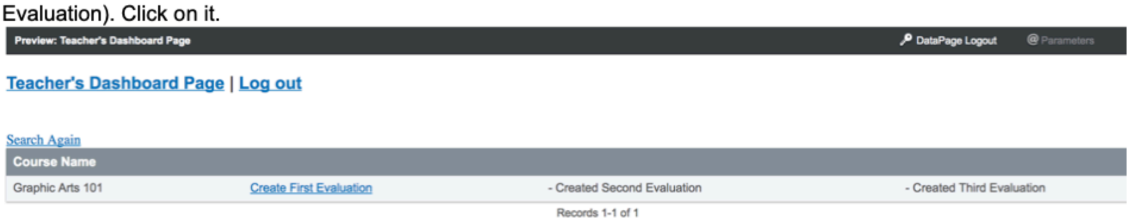


3. Click on **1.a. Evaluate a course**. You will be taken to the Course Selection page.

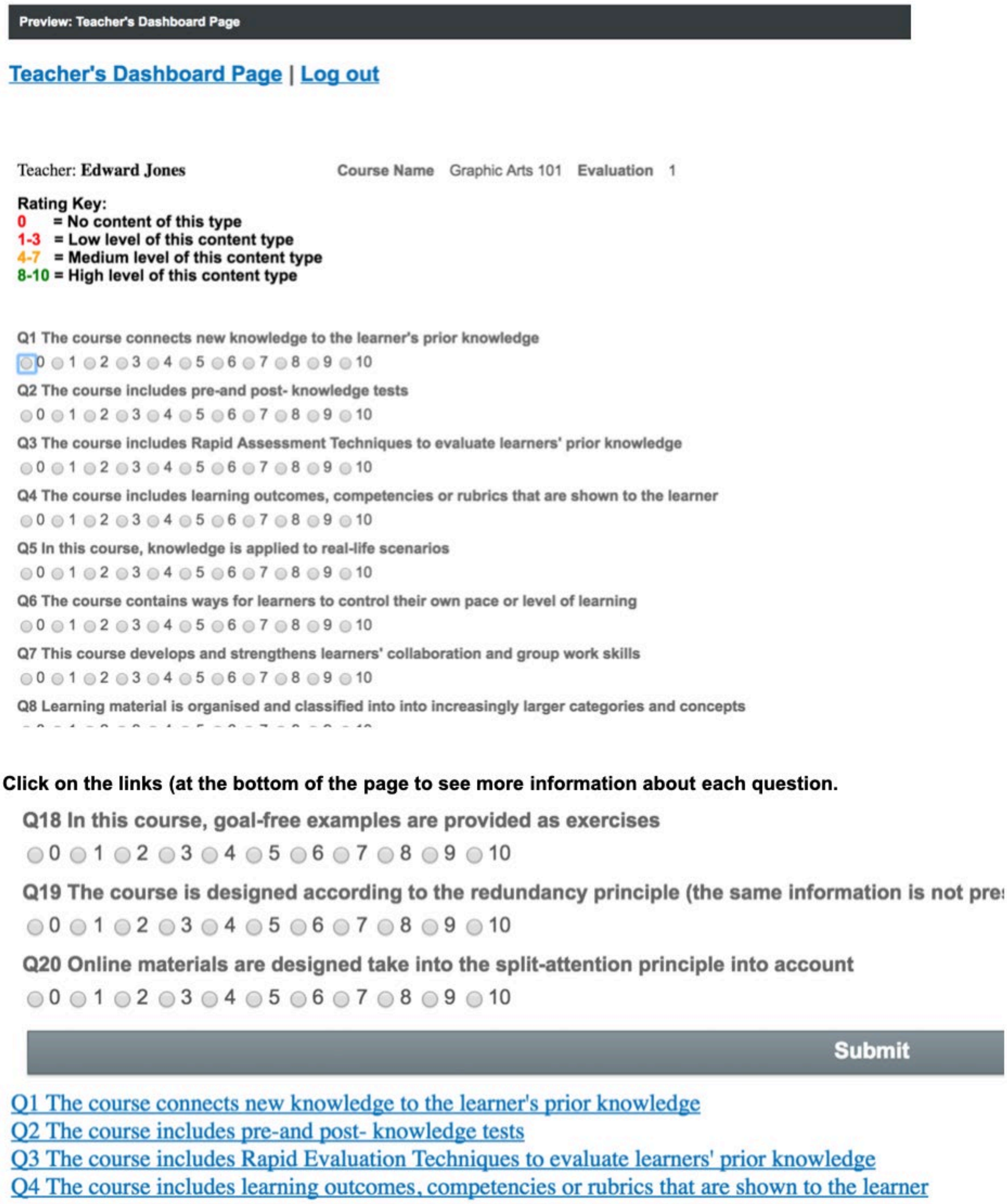


Your name will appear in the **Teacher Name** field. Click on the drop-down arrows under **Course Name** to select any course. Note the name of the course you selected as you will review it three times.

4. You will be taken to the Evaluation links. There are 3 links (for 3 iterations), but only 1 is active (Create First Evaluation). Click on it.

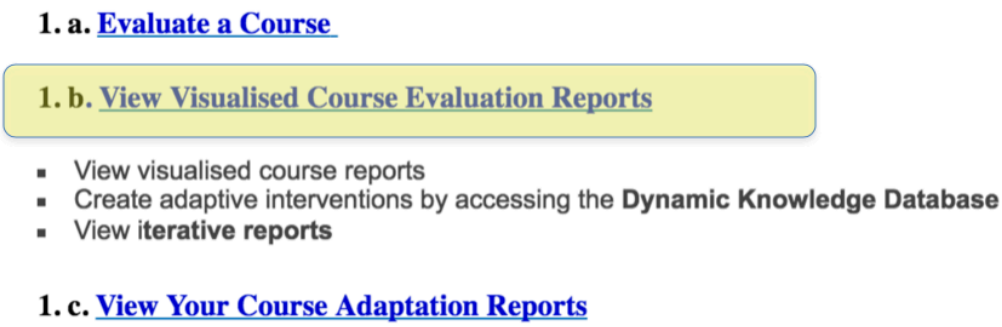


5. This will take you to a form with 20 statements about your course content (these statements are based on Cognitive Load Theory research evidence).
You will also see a Rating Key.
Complete the form (for the purposes of this focus group, use increasingly higher ratings in each of the 3 iterations).
Note: Scroll to the bottom of the page, where there are links to more information about each of the 20 statements.

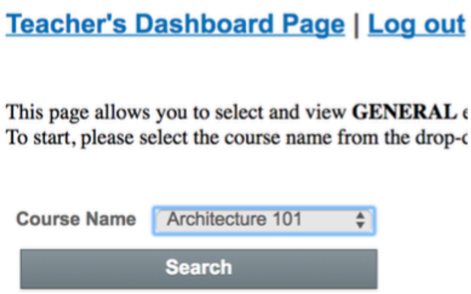

Preview: Teacher's Dashboard Page
Teacher's Dashboard Page | Log out
Teacher: Edward Jones
Course Name Graphic Arts 101 Evaluation 1
Rating Key:
0 = No content of this type
1-3 = Low level of this content type
4-7 = Medium level of this content type
8-10 = High level of this content type
Q1 The course connects new knowledge to the learner's prior knowledge
0 1 2 3 4 5 6 7 8 9 10
Q2 The course includes pre-and post- knowledge tests
0 1 2 3 4 5 6 7 8 9 10
Q3 The course includes Rapid Assessment Techniques to evaluate learners' prior knowledge
0 1 2 3 4 5 6 7 8 9 10
Q4 The course includes learning outcomes, competencies or rubrics that are shown to the learner
0 1 2 3 4 5 6 7 8 9 10
Q5 In this course, knowledge is applied to real-life scenarios
0 1 2 3 4 5 6 7 8 9 10
Q6 The course contains ways for learners to control their own pace or level of learning
0 1 2 3 4 5 6 7 8 9 10
Q7 This course develops and strengthens learners' collaboration and group work skills
0 1 2 3 4 5 6 7 8 9 10
Q8 Learning material is organised and classified into into increasingly larger categories and concepts
Click on the links (at the bottom of the page to see more information about each question.
Q18 In this course, goal-free examples are provided as exercises
0 1 2 3 4 5 6 7 8 9 10
Q19 The course is designed according to the redundancy principle (the same information is not pre
0 1 2 3 4 5 6 7 8 9 10
Q20 Online materials are designed take into the split-attention principle into account
0 1 2 3 4 5 6 7 8 9 10
Submit
Q1 The course connects new knowledge to the learner's prior knowledge
Q2 The course includes pre-and post- knowledge tests
Q3 The course includes Rapid Evaluation Techniques to evaluate learners' prior knowledge
Q4 The course includes learning outcomes, competencies or rubrics that are shown to the learner

When you have completed your form, click Submit.

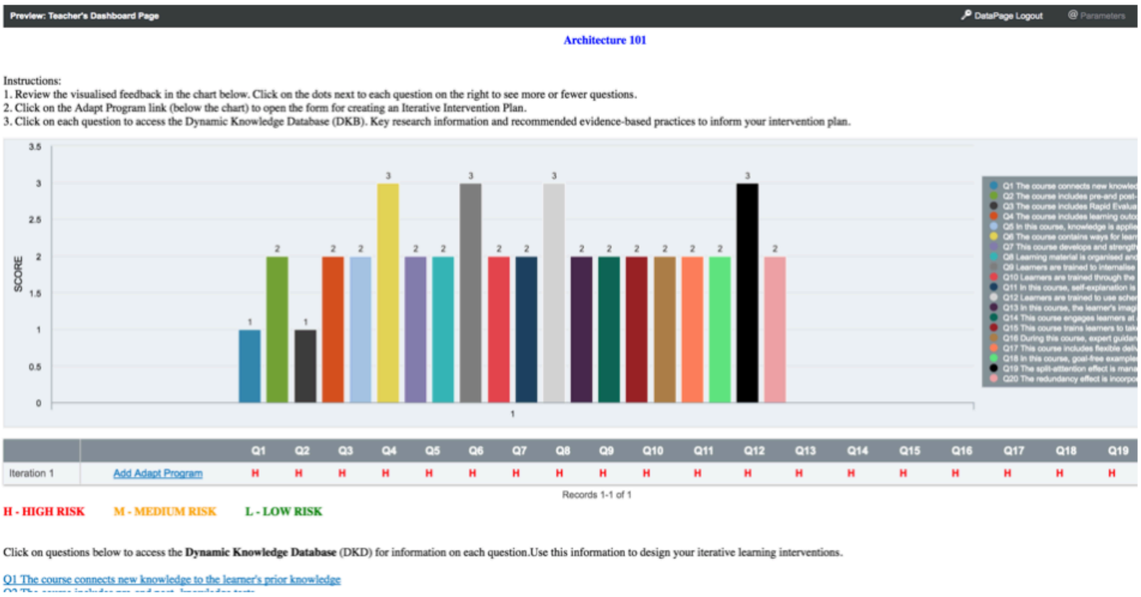
6. Now click on **Teacher's Dashboard Page** link at the top of the page and click on **1.b. View Visualised Course Evaluation Reports**



7. Select your course and click on Search:



8. You will access your **Review Page** showing the iteration you have just evaluated:
The bars on the bar graph show your ratings out of 10.
A risk rating appears below each bar - one per statement.
Lower scores represents a higher risks and higher scores represent lower risks.
The risk level (High-Medium or Low) is an indicator of the course not meeting the needs of novice learners.



9. You can now create interventions to modify your course.
Right- Click on **Add Adapt Program** and open it in a new Window.

The link will take you to the Adapt Your Course page.

This is a form for writing how you will adapt the course you have just evaluated.
(You do not have to adapt the course for every question parameter).

i. Select a Start Date and a Review Date for your intervention (red asterisk indicates a required field). This assists you to turn your intervention into a SMART goal.
ii. Check the first box to add notes from discussions with colleagues, faculty and/or department (required field).
iii. Check the boxes for each statement to open a text input field.

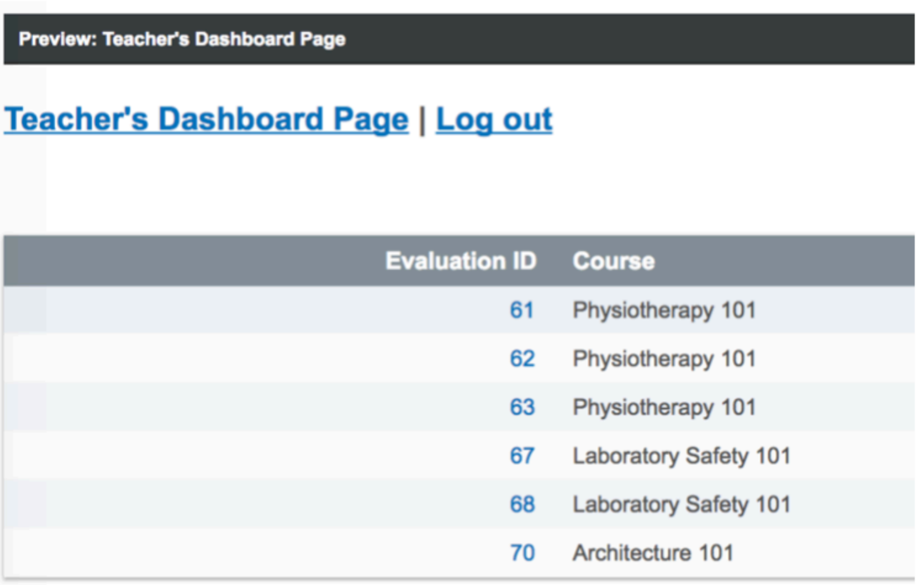
For each question, you can click on the blue hypertext to access the Dynamic Knowledge Database (DKD) for recommendations on how to strengthen your course. e.g. You can copy/paste recommended strategies or information from the DKD to your Adapt Program form.

NOTE: Phrase your goal in terms of advancing the demonstrated expertise of learners. The prompt is provided:

"How does this intervention manage the three types of cognitive load to advance learners towards higher levels of expertise?"

iv. When you have completed the form, Click on Submit.

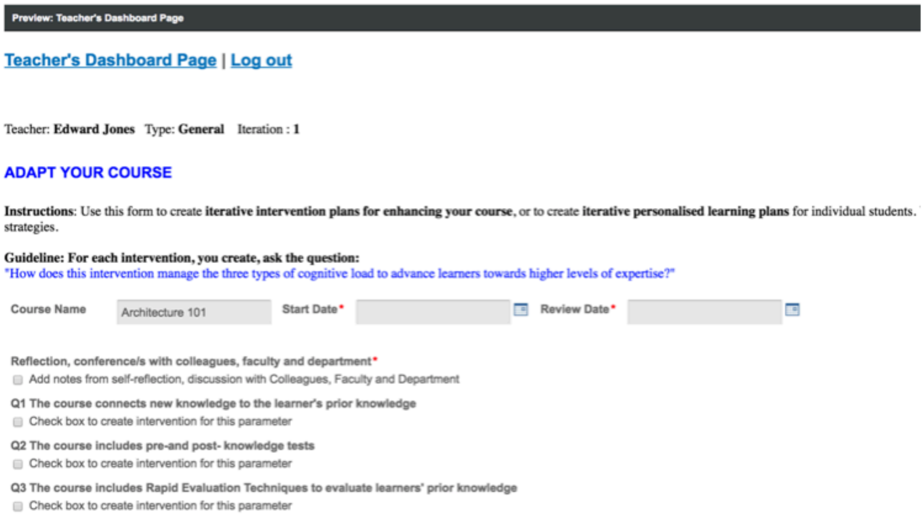
10. Now go to the **Teacher's Dashboard Page** and click on **1.c.** View your Course Adaptation Reports



Preview: Teacher's Dashboard Page

Teacher's Dashboard Page | Log out

Evaluation ID	Course
61	Physiotherapy 101
62	Physiotherapy 101
63	Physiotherapy 101
67	Laboratory Safety 101
68	Laboratory Safety 101
70	Architecture 101



Preview: Teacher's Dashboard Page

Teacher's Dashboard Page | Log out

Teacher: **Edward Jones** Type: **General** Iteration : **1**

ADAPT YOUR COURSE

Instructions: Use this form to create **iterative intervention plans for enhancing your course**, or to create **iterative personalised learning plans** for individual students. strategies.

Guideline: For each intervention, you create, ask the question:
"How does this intervention manage the three types of cognitive load to advance learners towards higher levels of expertise?"

Course Name Architecture 101 Start Date* Review Date*

Reflection, conference/s with colleagues, faculty and department*
Add notes from self-reflection, discussion with Colleagues, Faculty and Department

Q1 The course connects new knowledge to the learner's prior knowledge
Check box to create intervention for this parameter

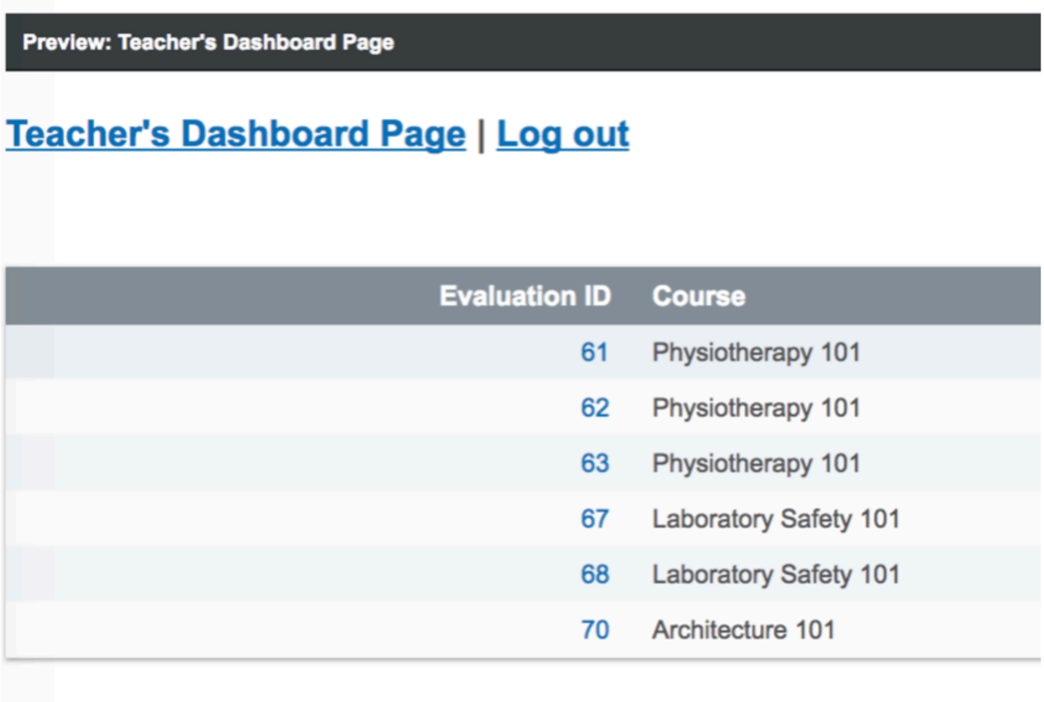
Q2 The course includes pre-and post- knowledge tests
Check box to create intervention for this parameter

Q3 The course includes Rapid Evaluation Techniques to evaluate learners' prior knowledge
Check box to create intervention for this parameter

10. Click on the Evaluation ID of the course you have just evaluated.
This will open a text version of the Adapt Program form you have just completed.
This is stored in the system for later reference and may be printed from the browser if required.

Implement the interventions you have noted in the form. i.e. add/modify your existing teaching approaches/resources according to your Adapt Program form.

Plan to conduct your 2nd evaluation



Preview: Teacher's Dashboard Page

Teacher's Dashboard Page | Log out

Evaluation ID	Course
61	Physiotherapy 101
62	Physiotherapy 101
63	Physiotherapy 101
67	Laboratory Safety 101
68	Laboratory Safety 101
70	Architecture 101

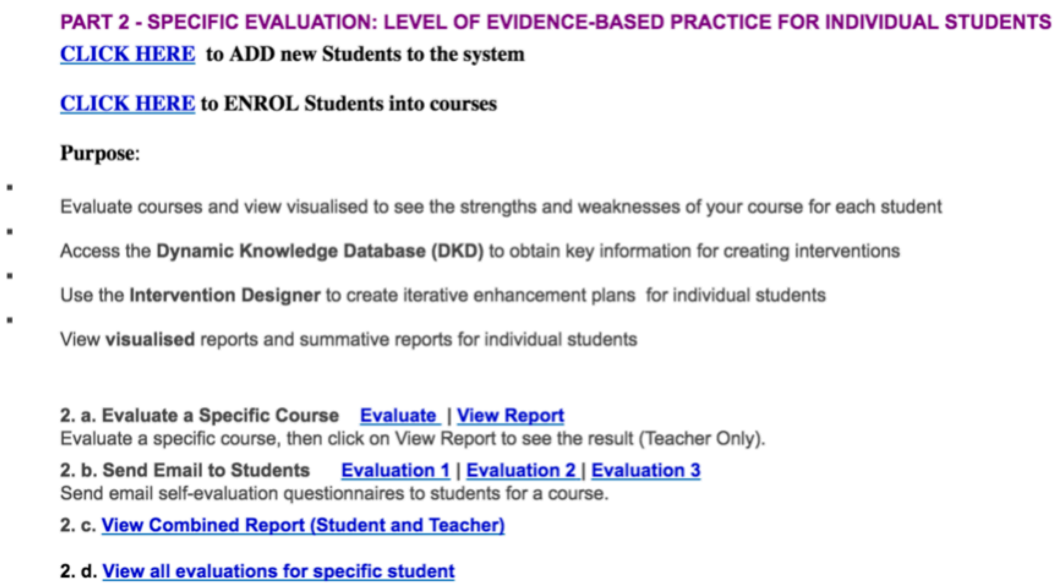
11. Repeat this process for three iterations to demonstrate evidence-based improvements in your course design. Click on **1.b**. View Visualised Course Evaluation Reports at any time to review iterative changes to your course/s.

PART 2: Specific Evaluation: Level of Evidence-Based Practice for Individual Students

1. On the Teachers' Dashboard, Click on **Enrol Students into Courses.**
Enrol the fictitious student whose details (Name, Surname and email address) you have been given.

Note: You will take the role of this students, so you will need to log into the Student's email address to confirm emails and complete evaluation forms.

2. On the Teacher's Dashboard, click on **2.a Evaluate**. This will enable you as a teacher to evaluate a course in the same way as you did in the GENERAL evaluation.



PART 2 - SPECIFIC EVALUATION: LEVEL OF EVIDENCE-BASED PRACTICE FOR INDIVIDUAL STUDENTS

CLICK HERE **to ADD new Students to the system**

CLICK HERE **to ENROL Students into courses**

Purpose:

- Evaluate courses and view visualised to see the strengths and weaknesses of your course for each student
- Access the **Dynamic Knowledge Database (DKD)** to obtain key information for creating interventions
- Use the **Intervention Designer** to create iterative enhancement plans for individual students
- View **visualised** reports and summative reports for individual students

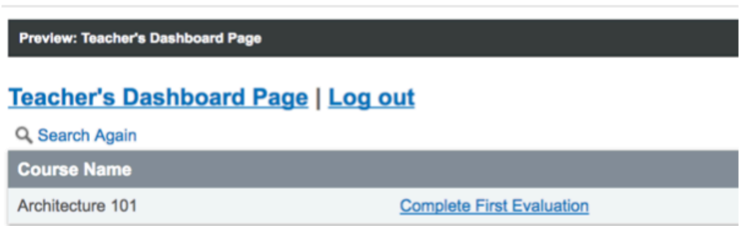
2. a. Evaluate a Specific Course Evaluate | View Report
Evaluate a specific course, then click on View Report to see the result (Teacher Only).

2. b. Send Email to Students Evaluation 1 | Evaluation 2 | Evaluation 3
Send email self-evaluation questionnaires to students for a course.

2. c. View Combined Report (Student and Teacher)

2. d. View all evaluations for specific student

2. Select your course from the drop-down menu and click on the 2. a Complete First Evaluation link.



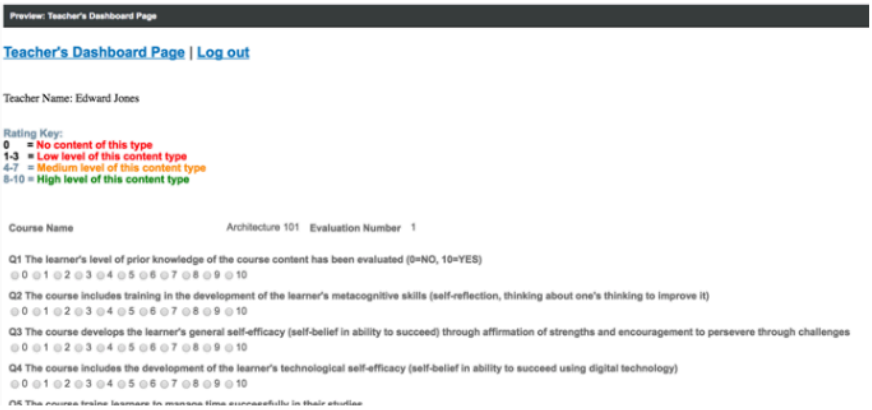
Preview: Teacher's Dashboard Page

Teacher's Dashboard Page | Log out

Search Again

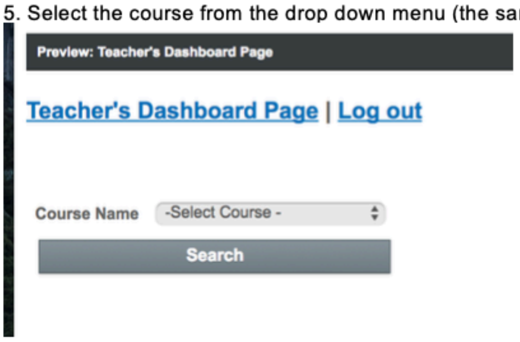
Course Name	
Architecture 101	Complete First Evaluation

3. The evaluation form will open.
Complete the form and click on Submit.



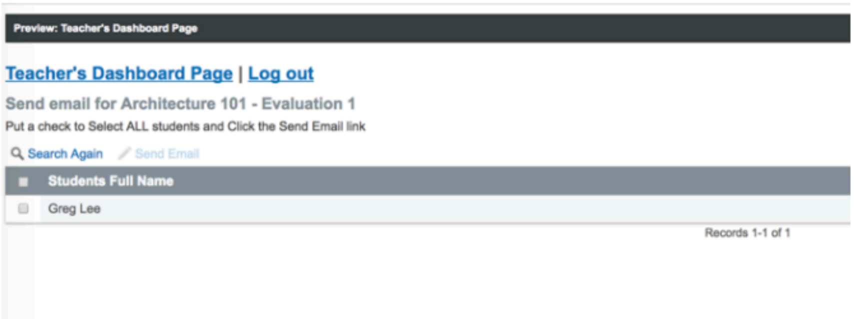
4. Now click on the Teacher's Dashboard Page link and click on **2.b.** Evaluation 1.

5. Select the course from the drop down menu (the same course you have just evaluated)



6. You will see the names of all students who are enrolled in the course.
Note: If student names do not appear, they are either not enrolled or have completed the evaluation for the particular iteration.

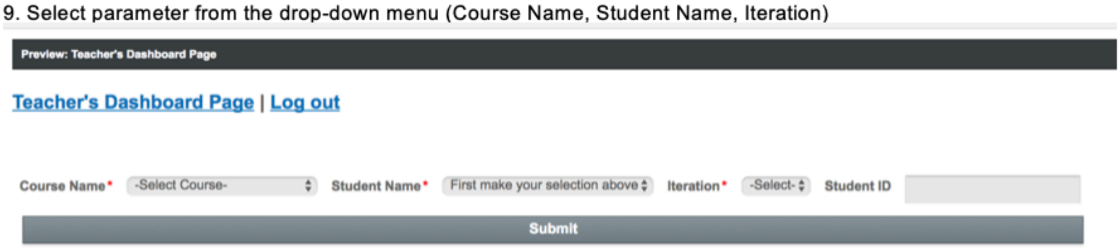
Select the students (check the boxes) and click on Send email.
An email will be sent to the student at https://webmail.optusnet.com.au/ with a link to the form.



7. Log into the student's account at the above Optus webmail link and click on the link to complete the evaluation (as a student), then click **Submit**.

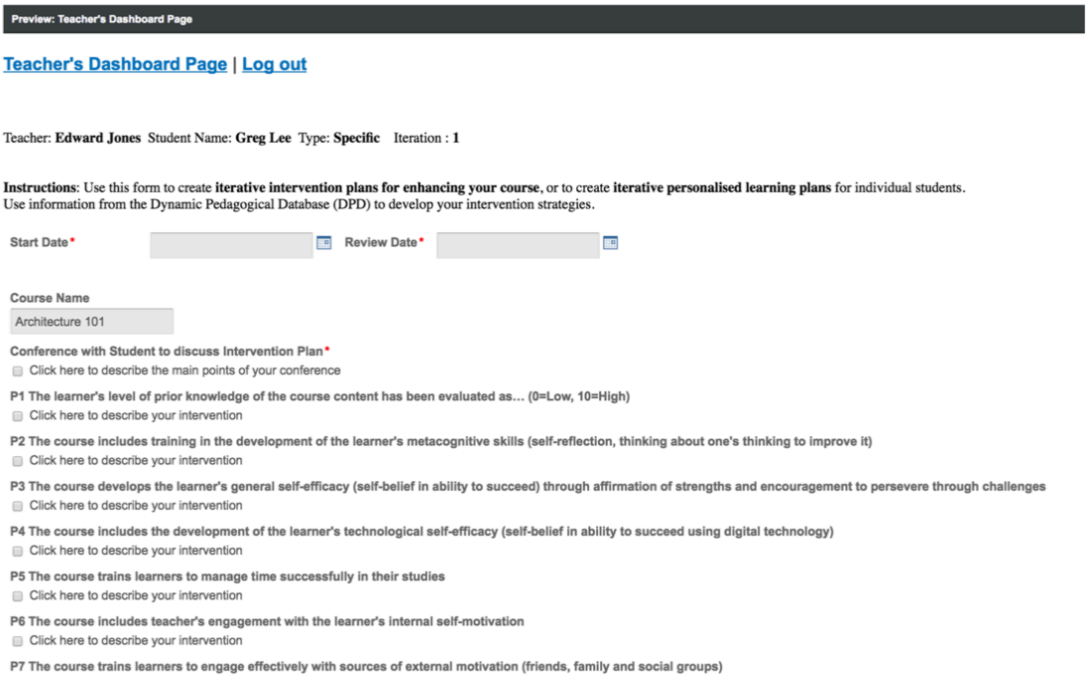
8. Now click of **Teacher's Dashboard Page** link
On the Teacher's Dashboard, click on **2.c**. **View combined report** (Teacher and Student)

9. Select parameter from the drop-down menu (Course Name, Student Name, Iteration)



10. The combined report for the specific iteration will display visually.
Note: Comparison bar graphs for Student and Teacher.
The report below the bar graphs displays the Risk Level for student having needs met and the course providing these needs.
The purpose of this report is for the teacher to compare strengths and weaknesses of both the course and the learner. This serves to inform decisions about strengthening the course for the individual learner.

11. Click on Create Student Adapt Program link (blue hyperlink).
12. The intervention form will open (similar to the GENERAL evaluation form).
Set a Start Date and A Review Date (SMART goal).
Click on check box to fill in required fields (fields with red asterisk).
Click on blue hypertext at the bottom of the page to access the Dynamic Knowledge Database (DKD) for recommended interventions derived from Cognitive Load Theory.
Create interventions by completing some or all of the fields related to the Parameters.


Preview: Teacher's Dashboard Page

Teacher's Dashboard Page | Log out

Teacher: **Edward Jones** Student Name: **Greg Lee** Type: **Specific** Iteration : **1**

Instructions: Use this form to create **iterative intervention plans for enhancing your course**, or to create **iterative personalised learning plans** for individual students.
Use information from the Dynamic Pedagogical Database (DPD) to develop your intervention strategies.

Start Date* Review Date*

Course Name
Architecture 101

Conference with Student to discuss Intervention Plan*
Click here to describe the main points of your conference

P1 The learner's level of prior knowledge of the course content has been evaluated as… (0=Low, 10=High)
Click here to describe your intervention

P2 The course includes training in the development of the learner's metacognitive skills (self-reflection, thinking about one's thinking to improve it)
Click here to describe your intervention

P3 The course develops the learner's general self-efficacy (self-belief in ability to succeed) through affirmation of strengths and encouragement to persevere through challenges
Click here to describe your intervention

P4 The course includes the development of the learner's technological self-efficacy (self-belief in ability to succeed using digital technology)
Click here to describe your intervention

P5 The course trains learners to manage time successfully in their studies
Click here to describe your intervention

P6 The course includes teacher's engagement with the learner's internal self-motivation
Click here to describe your intervention

P7 The course trains learners to engage effectively with sources of external motivation (friends, family and social groups)

13. Repeat this process for additional iterations.

14. Click on **Teacher's Dashboard Page** link
Click on **2.d.** View all evaluations for specific student.
Click on this link at any stage to view individual student progress/ continuous improvement.

Figure K.6 CLEMS Operating instructions provided to participants in Focus Group 3

Notes: As outlined in Chapter 1 the name CLEMS was used to identify the instrument in the final stage of research. However, during research the instrument was referred to as "the instrument" and "CLASS" (Cognitive Load Adaptive Software System).

Appendix L: Focus Group 1 - Summary of Raw Data

This appendix provides a summary of the raw data responses from the participants in Focus Group 1, titled Designing CLEMS. Details of the focus group are in Table L1 below:

Date of Focus Group: 14 June 2016

Venue: University of Adelaide, Faculty of Education

Table L.1 Primary and secondary roles declared by the 15 participants in Focus Group 1

Participants	Role
1	Instructional Designer (Learner)
2	Academic (Educator)
3	Academic Researcher (Educator, Instructional Designer, Learner)
4	Instructional Designer
5	Instructional Designer
6	Educator
7	Educator
8	Academic
9	Academic
10	Educator
11	Academic
12	Academic
13	Educator
14	Educator
15	Educator

Note: This table indicates the key roles of participants, with secondary roles indicated by in parentheses.

The feedback responses from Focus Group 1 were coded in key categories. As the theme of the Focus Group was "Designing CLEMS," the following coding system was used to classify responses from participants. The purpose of coding was to assist with the process of identifying higher-level themes for organising responses. No quantitative techniques were applied to the numbers of codes collected, as they were used to identify and clarify thematic areas, as follows:

1. Theory (Th)

Responses relating to theoretical aspects of CLEMS

2. Technical and Systemic (T&S)

Responses relating to technical functions of CLEMS

3. Content and information (C&I)

Responses relating to content and information within CLEMS

4. Teacher (T)

Responses relating to the role and functions of the teacher

5. Learner (L)

Responses relating to the role and functions of the learner

Note: Speech marks indicate verbatim participant responses and regular text indicates commentary and discussion by researcher.

The collated comments appear in the next section, each with codes.

Responses to Form 1A: Learner Profile Parameters

Rate the level of importance (none, low, medium, high) including these *learner* evaluation parameters in CLEMS.

Note: Each non-response (blank) results in a negative score of 1 (Blank column).

Table L.2 Form 1A: Rating of learner profile parameters for inclusion in CLEMS

Number	Parameter	Blank (-)	None	Low	Med	High	Total
1	The level of the learner's prior knowledge of the subject	0	0	2	2	11	**15**
2	The level of the learner's metacognitive skills (reflective learning ability, ability to separate concepts from knowledge)	0	0	1	4	11	**15**
3	The learner's self-efficacy (general self-belief in ability to succeed)	0	0	2	3	10	**15**
4	The learner's digital literacy self-efficacy	0	1	3	7	4	**15**
5	The learner's time management self-efficacy	1	2	6	2	4	**14**
6	The learner's motivation - internal (desire to engage in learning)	0	0	1	4	10	**15**
7	The learner's motivation - external (community/family pressure, perceived need of learning)	0	2	2	5	5	**14**
8	The time elapsed since the learner last engaged in formal learning	0	0	0	4	11	**15**
9	The learner's language proficiency in the language of instruction	0	0	0	4	11	**15**
10	The learner's social learning self-efficacy (confidence in engaging/interacting with peers, groups/teacher)	0	0	1	6	8	**15**

Notes: Comments on specific Learner Profile Parameters:

#2: This is a pivotal consideration.

#3: This parameter is too tenuous/slippery, difficult to measure

The issue raised in comment #3 is well-researched and should not present undue challenges. See Klassen and Usher (2020)–Motivation.

FORM 1A Comments (Parameters referred to as Q:)

Q1: [Prior knowledge:]

'It is about the learning process rather than what they know about a subject'. **(L)**

Cognitive load theory, which is based on an extensive foundation in expertise research, contradicts this point. De Groot (1965) established the domain specificity of expertise, which has been validated through additional research (e.g. Chase & Simon, 1973; Chi, 2000, 2006a; Tricot & Sweller, 2013). In CLT, the *information store* principle (Sweller, Ayres & Kalyuga, 2011, pp. 17–25) affirms the critical need for domain-specific knowledge to remain the focus of learning.

'But how well do learners know what they know?' **(L)**

Research by Halabi (2004) referenced the finding that recent, in-depth study of concepts relevant to the concepts being learned was valuable as prior knowledge, but distant and weakly-related content did not strengthen learning. Sweller, Ayres & Kalyuga (2011, pp. 204–206) outlined research that pointed to the need for pre-training, focusing on sub-goals and presenting procedural and declarative knowledge separately to reduce cognitive load.

'In terms of novice-to-advanced spectrum - different techniques [required]'. **(T)**

'How to measure this? Learner's self-analysis?' **(T&S)**

'Needed for base levels. Dependent on intrinsic cog. Load'. **(Th)**

‘Teacher interview. Learning program specific’. **(T)**

‘Pivotal need to know. What is short or long-term memory. Novice or expert’. **(Th)**

Q2: [Reflective learning:]

‘Some learners may not know what “reflective” learning is’ **(L)**

‘Could be [a higher importance level] but to date the research I’ve read indicates the causality isn’t clear i.e. increasing metacognition [for] improving outcomes”. **(Th)**

‘Important across subjects’. **(Th)**

‘Pivotal. **(Th)**

‘Pivotal’. **(Th)**

‘I think this may depend a bit on their previous knowledge’. **(L)**

Q3: [Self-efficacy]

‘This can only ever be perceived, not conclusively evaluated?’ **(L)**

‘Sometimes self-efficacy can be a motivator’. **(T)**

‘But difficult to measure’. **(Th)**

‘Essential to the design’. **(Th)**

‘Too tenuous/slippery to measure effectively. Why have self-efficacy? Makes something hard to measure eccentricities’. **(Th)**

While a considerable research base exists on self-efficacy, the specific instruments for use in particular contexts can present challenges (cf. Bandura, 2006; Klassen & Usher, 2010; Vasile, Marhan, Singer & Stoicescu, 2011).

‘This may reflect the students’ barriers to learning such as fear’. **(Th)**

‘How to determine this? **(Th)**

Q4: [Learner's digital literacy self-efficacy:]

'Students often have the wrong idea about their own digital literacy'. **(L)**

'It would all depend on the subject'. **(C&I)**

'Dependent on course'. **(C&I)**

'How to determine this?' **(Th)**

There is a growing research base in developing instrument for determining the parameter of digital literacy e.g. Covello & Lei, 2010).

Q5: [Learner's time-management self-efficacy:]

'Students often have the wrong idea about their own time management self-efficacy'. **(L)**

'Could be [a higher importance level] but to date the research I've read indicates the causality isn't clear [between learner's time-management self-efficacy and learning outcomes'. **(L)**

'Good instructional design would already have milestone assessment tasks, for example, to support students with time-management problems. If I find that a student has time-management [problems] I'm not sure that I could do much more (including encouragement) that I would not be doing generally. Therefore, what valuable intervention would I use?' **(T)**

'Is this necessary in this instrument?' **(Th)**

'This may be more important with post-grad learners'. **(L)**

'How to determine this?' **(Th)**

Q6: [Learner motivation-internal:]

'Could be addressed by the tool as it "suggest[s]" different strategies for learning when learning is not happening'. **(L)**

'Low motivation: need activities linked to summative results. High motivation: can have separate, independent, formative activities'. **(T)**

‘It’s going to be variable and situational’. **(Th)**

‘But hard to measure’. **(Th)**

‘But risky in the measurement’. **(Th)**

‘Motivation to learn will effect everything else’. **(Th)**

Q7: [Learner motivation-external:]

‘Nothing I can do’. **(T)**

‘But how do you collect/find this information? Some students may not share this with you’. **(T)**

‘Hard to measure’. **(Th)**

Q8: [Time since learner engaged in formal learning:]

‘Use of learning design will take care of this’. **(C&I)**

‘We have many learners in this category and may exclude in learning, but it does contribute to other variables’. **(C&I)**

Q9: [Proficiency level in language of instruction:]

‘This should be externally verified - students overestimate these abilities’. **(T)**

‘Very important, as are cultural factors related to birth language and experience of education’. **(L)**

‘Hard to assess. Discipline-specific language? English’. **(T)**

Q10: [Social learning self-efficacy:]

‘Is very important as most learning will happen in an informal way prior to school and outside the school context, hobbies, interests, sports, etc'. **(L)**

'Online vs. face-to-face discussion for example'. **(L)**

'I think that this is largely context-specific'. **(Th)**

'This is very important for students who need to work in groups. Depends on teaching mode. PBL. TBL. Case-based learning'. **(Th)**

Responses to Form 1B: Learning Course/Program Parameters

Rate importance (none, low, medium, high) of including these course/program rating parameters in CLEMS.

Note: Each non-response (blank) results in a negative score of 1 (Blank column).

Table L.3 Form 1B: Rating of Course/Program Parameters for inclusion in CLEMS

Number	Parameter	Blank (-)	None	Low	Med	High	Total
1	How learning activities are linked to prior knowledge	2	0	0	3	10	**13**
2	If pre- and post-tests are included in learning activities (diagnostic assessment)	1	0	2	5	7	**14**
3	If rapid evaluation techniques are included to test learner prior knowledge (Cognitive Load Theory)	2	0	1	4	8	**13**
4	If learning outcomes are included in the learning program	1	1	1	1	11	**14**
5	If real work/life applications are included in learning materials (e.g. case studies)		1	1	4	9	**15**
6	If learning is structured for learner control (videos, audio recordings, online learning modules)	0	1	0	3	10	**14**
7	If learning is designed to include social	2	1	1	5	6	**13**

	presence (collaboration, group work)						
8	If learning material is organised into schemas (internalised organisational principles and structures) and knowledge, such as factual information	2	1	1	2	9	**13**
9	If learning is organised into higher-level chunks, categories, principles, concepts, linked information, as opposed to a linear, knowledge-based approach	1	0	1	4	9	**14**
10	If learning concepts are validated before knowledge is taught (i.e. learners demonstrate conceptual understanding, internalisation of concepts and principles)	0	0	1	5	8	**15**
11	If worked examples, completion problems and full examples are provided in learning program*******	0	1	2	5	7	**15**
12	If self-explanation is taught as a skill within the learning program	1	1	2	4	7	**14**
13	If schema validation skills are taught (concept mapping, graphic representation of concepts, verbal explanation of processes by learners)	0	0	2	3	10	**15**
14	Numbering error - no parameter #14 was included in this form						
15	If the learner's imagination is engaged in learning******	2	0	1	2	10	**13**
16	If emotional engagement is facilitated in learning materials (stories, anecdotes, rules of thumb) *[are used] to provide relevance and meaning to learning	1	0	2	3	9	**14**
17	If expert guidance is accessible by learners	1	1	0	1	12	**14**
18	If flexible delivery time is available to	1	0	0	3	11	**14**

	support schema development (deep understanding of underlying structure of learning, flipped classroom, **[p]re-learning						
19	If goal-free examples are provided as exercises	0	0	2	3	9	**14**
20	If the split-attention effect is reduced/eliminated (i.e. graphic and textual material ***[formatted] in close proximity	3	0	2	3	7	**12**
21	If the redundancy effect is recognised (extraneous or irrelevant material reduced/removed ****[from] program	2	0	2	1	10	**13**
22	If means–ends analysis is avoided as a learning strategy	2	1	3	4	5	**13**
23	If unsupported learning is avoided	2	3	4	2	4	**13**
24	If the modality effect is recognised and used	2	0	0	3	10	**13**
25	If risk associated with learning (hazardous materials) [is considered as a factor in learning]	2	3	1	1	8	**13**

It is noted that a numbering error occurred in this form, which consisted of 24 parameters. Question 14 has been left blank.

*[ ] = removed to provide greater coherence to parameter

**[p] = typographical error corrected

***[formatted] = added

***** [from] = typographical error corrected

***** [is considered as a factor in learning] = words added to complete sentence

******The imagination effect in cognitive load theory has a specific meaning and this should be clarified further in future research (Sweller, Ayres & Kalyuga, 2011, pp. 183–192)(see Imagination Effect)

*******The terms *worked, faded and full examples* were used in focus groups. *Faded* was used to describe completion problems and *full examples* was used to describe traditional problem tasks without prompts or scaffolding for learners (Sweller, Ayres & Kalyuga, 2011, p. 106).

FORM 1B Comments (Parameters referred to as Q:)

Q1: [Learning activities linked to prior knowledge:]

‘Informs scaffolding of knowledge’. **(L)**

‘How effectively? The manner in which they are linked? Extent to which they are explicit statements of linkage’. **(L)**

‘Need to build on learning’. **(T)**

Q2: [Pre- and post-tests:]

‘Could be high or low priority - but could these diagnostics be standardised?’ **(L)**

‘There are other forms of assessment and checking’. **(Th)**

‘We need to be able to measure impact’. **(T)**

‘Would all depend on time. Would assessment cover post-test?’ **(T)**

Q3: [Rapid evaluation techniques]:

‘Can lead to branching to remediate before advancing, if required’. **(L)**

‘Would this be fair for all students?’ **(L)**

Q4: [Learning outcomes included]:

‘Constructive alignment is essential’. **(Th)**

‘They are as a matter of course in my subjects’. **(Th)**

‘As long as students are guided to them and they understand them’. **(Th)**

‘Not sure the students read these although I think they are important’. **(Th)**

‘Reasonable assumption that they are! This is now a regulatory requirement!’ **(C&I)**

Q5: [Real-life* contexts of learning]:

‘Provides meaning/motivation, especially when these are in the summative assessments’. **(L)**

Real-world, authentic contexts for learning need to be carefully structured to avoid cognitive overload and to ensure that learner have sufficient prior knowledge to engage meaningfully in these learning environments.

‘Depends of subject matter/topic’. **(C&I)**

‘Can improve motivation for some students. Possible recommended intervention’. **(L)**

‘They are as a matter of course in my subjects’. **(T)**

‘But timing is important’. **(T)**

‘Very important for professional learning’. **(T)**

Q6: [Learner control:]

‘Show options for how learner can engage with content’. **(L)**

‘Has strong ties with building self-efficacy’. **(L)**

‘They are as a matter of course in my subjects’. **(T)**

‘Students need to be able to pace their own learning and go back over or identify concepts they don’t understand’. **(L)**

Q7: [Social presence:]

'Social presence is not necessarily required for learning to occur. Perhaps include teacher-presence here?' **(L)**

'It may impact motivation and improve learning. But not for all students'. **(L)**

'Subject dependent'. **(L)**

'They are as a matter of course in my subjects'. **(T)**

'All depends on the group. Some succeed in learning without social pressure'. **(L)**

'Dependent on course or subject. Very important in professional specific learning'. **(L)**

Q8: [Learning separated into schemas and knowledge:]

'Only useful if worked examples occur to demonstrate use of schemas'. **(T)**

'They are as a matter of course in my subjects'. **(C&I)**

Q9: [Learning organised into higher-level chunks:]

'Depends on the (a) level of the learner; (b) position on Bloom's taxonomy'. **(L)**

Q10: [Learning concepts presented before knowledge is taught:]

'Depends on the subject being taught and learned'. **(L)**

Q11: [Worked, faded and *full examples provided:]

'This allows the student to identify their own problems in learning and 'reset' learning'. **(Th)**

The term *full examples* is used for traditional examples where learners are required to complete every step of the problem without any scaffolding provided (see Full Examples)].

Q12: [Self-explanation:]

‘Great way to learn by explaining (to others usually)’. **(L)**

‘But would depend on language levels of students i.e. International students may not be comfortable/understand this’. **(L)**

Q13 [Using schema validation skills:]

Respondents unanimously indicated the necessity for the inclusion of schema validation skills as part of the learning process.

Q14 Numbering error - no parameter #14 was included this form.

Q15: [Imagination:]

‘This would be difficult prior to a course starting, so may have limited diagnostic value’. **(L)**

‘You’d kind of hope that this was happening by default’. **(T)**

‘I think this is very dependent on the course being taught’. **(C&I)**

Q16: [Emotional engagement:]

‘Extremely important to build emotional responses into teaching, helps to move memory to long-term memory’. **(L)**

‘This is particularly important in professional learning’. **(L)**

Q17: [Expert guidance available:]

‘This should always be true’. **(C&I)**

Q18: [Flexible delivery time:]

‘Yes, everyone learns at different speeds - it just means they are not there yet’. **(L)**

‘This (in theory) would give some insight into the relative value of these approaches’. (**C&I)**

Q19: [Goal-free examples]:

‘Formative? Only if linked to summative, or formative exercises mirror summative’. (**Th)**

‘Takes away the anxiety in learning’. **(Th)**

Q20: [Split-attention**]:

‘Not sure why they wouldn’t be in close proximity’. **(Th)**

‘You’d hope this was happening automatically. **(Th)**

It should be assumed that the format of learning materials follow the principles of spatial and temporal contiguity (Mayer, 2005, p. 6; Ginns, 2006), strategies which considerably strengthen learning for novices.

Q21 [Removing redundancy in learning materials:]

Responses strongly indicated the necessity to remove redundancy from learning materials. **(Th)**

Q22 [Means–ends analysis avoided in learning interventions]

Responses strongly indicated the necessity for removing means–ends analysis from learning materials. **(Th)**

Q23: [Unsupported*** learning:]

‘There needs to be some unsupported learning’. **(Th)**

[The use of unsupported learning may result in learners "floundering" (Clark, 2013, pp. 6, 73, 141) unless care has been taken to ensure sufficient prior knowledge exists (cf. Kirschner, Sweller & Clark, 2006; Sweller, Ayres & Kalyuga, 2011, pp. 171–182)].

Note: Question number 24 was erroneously omitted from this form.

Q25: [Risk associated with learning:]

‘This should be done without the system’. **(C&I)**

‘Could this apply to approaching exams since exams are high stakes/risk in learning and achieving’. **(L)**

‘Probably a good idea to avoid litigious situations’. **(T)**

‘Where required’. **(L)**

*Terms such as *real-world or real-life* applications may be too complex and confusing and therefore lead to poorer form of learning. This argues for great care in the selection, wording and sequencing of real-world applications e.g. case studies, in the learning sequence.

**The expectation that split-attention in teaching should occur automatically may be unrealistic as a general principle. Due to the heavy cognitive load imposed on working memory for novices during learning, great attention should be paid to the format of instructional design, both on paper pages and in multimedia environments to ensure that split-attention is eliminated (Sweller, Ayres & Kalyuga, 2011, pp. 111–128).

***The stage at which unsupported learning is introduced for novice learners requires careful consideration of the learner’s prior knowledge and the format of instruction (Sweller, Ayres & Kalyuga, 2011, pp. 171–182; Martin, 2016)(see Guidance Fading Effect).

Responses to Form 1C: Instrument characteristics

Rate importance (none, low, medium, high) of including these characteristics in CLEMS:

Note: Each non-response (blank) results in a negative score of 1 (Blank column).

Table L.4 Responses to Form 1C: Rating of characteristics for inclusion in CLEMS

Number	Parameter (CLEMS should ...)	Blank (-)	None	Low	Med	High	Total
1	Evaluate the extent to which the learning material links practice to a theoretical model	2	0	1	8	4	**13**
2	Include a Learner Profile (see Learner Profile Form 1B)	2	0	0	3	10	**13**
3	Include a Learning Program Profile analysis (see Learning Program Profile Form 1A)*	2	0	1	1	11	**13**
4	Enable the teacher to select specific Learning Program parameters to evaluate (Form 1B)**	2	0	0	1	12	**13**
5	Provide suggested intervention strategies for strengthening learning [recommender system]	2	0	0	0	13	**13**
6	Enable the teacher to record a description of intervention strategies for the learner	2	0	1	3	9	**13**
7	Be sustainable through community ownership	2	0	2	5	6	**13**
8	Be extensible (adaptable/modifiable to include new evaluation parameters)	2	0	0	3	10	**13**
9	Be administered by the teacher rather than being administered by the system	2	0	4	0	9	**13**
10	Be database driven (stores all data for current/later analysis)	2	0	0	0	13	**13**
11	The instrument is rapidly deployed (fast analysis and feedback to inform choice of	2	0	0	2	11	**13**

	learning interventions e.g. radio buttons/sliders to select parameters)						
12	Be cloud-based (universally available, scalable)	2	0	1	3	9	**13**
13	Be developed in the form of an application (app) that is downloadable from Google and Apple stores	2	0	2	5	6	**13**
14	Store and track student progress information (identify, learning profile) for future use	2	0	2	2	9	**13**
15	Provides visualise[d]* data output expressing strengths and weaknesses of the learning program	2	0	0	3	10	**13**
16	Provides textual data output expressing strengths and weaknesses of the learning program	2	0	1	6	6	**13**
17	Be experiment-based	2	1	1	4	7	**13**
18	Be educative for users (provide users with theoretical basis and research evidence for intervention strategies)	2	0	0	5	8	**13**

* Form 1A = corrected. Original stated form 1C

** Form 1B = corrected. Original stated form 1A

*** [d] =typographical error corrected

FORM 1C Comments (Paramaters referred to as Q:)

Q3: [Teacher selection of evaluation parameters:]

‘There may be policy restrictions imposed on teacher’. **(T)**

‘Very high in practice-based disciplines’. **(C&I)**

Q5: [Intervention strategies suggested]:

‘Yes!’ **(C&I)**

‘Isn’t this its purpose?’ **(T&S)**

Q7: [Sustainable through community ownership:]

‘…unless you can find somebody to bankroll it’. **(T&S)**

‘Otherwise it will not be used’. **(T&S)**

Q8: [Extensibility:]

‘Can’t think of any extensions yet’. **(T&S)**

‘Needs to be a flexible framework to include future research’. **(T&S)**

Q9: [Administered by teacher:]

‘Needs to happen at a ‘grass roots’ level’. **(T)**

Q10:[Instrument is database driven:] “

‘Teacher feedback!’ **(T)**

‘And for other users *meta-tags’. **(T&S)**

Q11: [Rapid deployment of instrument:]

‘Must be, or will not be used’.

Q12: [Cloud-based, universally available, scalable:]

‘Also universal platform so accessible on any device’.

Q13: [The app format:]

‘Would be great for on the fly analysis’. **(T)**

‘Mobile devices?’ **(T&S)**

‘Good, but as long as it’s browser based can access on mobile’. **(T&S)**

Q14: [Storage of student information for future use:]

‘Make sure info is secure and private’. **(T&S)**

‘Future use by whom? Who can access data?’ (**C&I)**

‘Maybe higher [level of importance] if evidence of link between specific students and types of intervention’. **(Th)**

‘May result in bias’. **(Th)**

‘Secure. Transferable. Authorities?’ **(C&I)**

Q15: [Visualised data output:]

‘For ease of use this would be great’. **(T&S)**

‘Graphs are helpful for processing the details’. **(T&S)**

‘Easy to analyse’. **(T&S)**

Q17: [Experiments:]

‘Not sure what this means. Only to be used in experiments?’ **(T)**

‘Evidence-based’. **(Th)**

‘Not sure we have much time in a semester to do this’. **(T)**

Q18: [Educative aspect of the instrument:]

‘As long as user isn’t overloaded’. **(T)**

‘As an option’. **(T)**

‘May be useful for at-risk students’. **(L)**

Post-Focus Group 1 Participant Rating

L.5 Rating scale key: Participants rated items on a low-to-high scale of 1–10

The ratings in column 3 indicate the individual, comma-separated responses by participants, with calculated averages.

Table L.5 Post-Focus Group 1 participant rating form

Number	Rating Item	Rating 1–5 and comments (where applicable)
1	The purpose of the focus group was clearly explained	Ratings: 4, 5, 4, 5, 5, 4, 5, 5, 3, 4, 3 Average: 47/11=4.27
2	Housekeeping/safety/conditions were explained	Ratings: 4, 2, 4, 4, 4, 5, 2, 5, 5, 1, 1 Average: 37/11=3.36
3	Ethics forms and rights of participants were clearly explained	Ratings: 5, 5, *, 5, 5, 5, 5, 5, *, 2, 5 Average:47/11=4.27
4	Form 1 A was clear and easy to follow	Ratings: 4, 5, 4, 3, 5, 4, 4, 4, 4, 4, 4 Average: 45/11=4.09
5	Form 1 B was clear and easy to follow	Ratings: 4, 5, 4, 3, 5, 3, 4, 4, 4, 4, 3 Average: 43/11=3.9
6	Form 1 C was clear and easy to follow	Ratings: 4, 5, 4, 3, 4, 5, 4, 4, 4, 4, 4 Average: 45/11=4.09
7	I learned about Cognitive Load Theory from this Focus Group	Ratings: 5, 5, 3, 5, 4, 5, 5, 4, *, 5, 4 Average:45/11=4.09
8	I learned about technology in education from this Focus Group	Ratings: 2, 3, 3, 4, 3, 3, 2, 2, *, 2, 3 Average: 27/11=2.45
9	If the instrument was ready today, it would be useful to me as an educational practitioner	11 Affirmative responses. Additional comments: 'Definitely - looks likely this tool will be a valuable resource'. 'Yes, but I would have to evaluate the time factor involved'. 'Yes! But my concern is scale. My classes are 40-90 students in size (3-4 classes/semester) so not

		sure how easy it would be to use" ‘I think it sounds like a worthwhile thing, but my role currently is staff/IT systems oriented". "Yes, as I am researching cognitive load theory informal instruction in first year computer science’.
10	This Focus Group would have been better if ...	‘Clearer signposts at the beginning’. ‘More time unpacking a number of the key terms’ (glossary useful; but too brief) ‘An example of a learner profile was provided.’ ‘The Glossary was provided ahead of time’. ‘The Glossary/Terminology was provided ahead of time. ‘Description made it appear to be about course design instead of student intervention suggestions and tracking (learning management)’.

- (asterisk) signifies missing data

Appendix M: Focus Group Procedures

Introduction: Effectiveness of the focus group method

Morgan (1988, p. 17) states that "The simplest test of whether focus groups are appropriate for a research project is to ask how actively and easily the participants would discuss the topic of interest".

The focus group discussion aligned with the general procedural guidelines provided by Ulin, Robinson and Tolley (2005, pp. 229–231), who recommend the following 6-stage checklist in preparing and running a focus group. Expanded examples of content are provided under each stage based on considerations arising from each focus group.

Instructions:

1. Prior to leaving for the focus group site:

- Review protocols, gather materials, prepare resources
- Verify with supervisors and other stakeholders

2. At the site, prior to the commencement of discussions:

- Set up room, check technology, greet participants, distribute forms and comply with ethics requirements

3. Initiating the focus group discussions:

- Welcome the participants, conduct introductions
- Define the purpose of the study
- Explain process and requirements for the focus group
- Verify understanding of processes and procedures where required

4. Conducting and managing the discussion:

- Ask open questions, ask participants their opinions on questions, draw on expertise of participants, ask probing questions, ask clarifying questions such as:

  - Do you mean…?
  - What other methods do you know…?
  - How does that relate to…?
  - Does anyone else relate to that…?
  - In your situation, how would you…?

- Identify contrasting views, new areas requiring investigation, body language of participants, be aware where clarification of terminology or process is required

5. Concluding the discussion:

- Thank the participants, remind participants how information will be used
- Ask participants to complete post-focus group feedback form

6. Post-discussion considerations:

- Summarise notes, collate data, code data, organise data, interpret data, compare data between focus groups (triangulation) and confirm/disconfirm emerging findings with ongoing literature reviews.

Format engaged for the current study

The participants in this study were recruited for their qualifications and experience as well as their willingness to share ideas and contribute to the discussions. This requirement was explicitly stated in the advertising material distributed to potential participants via the website (elearningdesignphd.com), via advertising flyers and in emails sent to invitees. More than ninety percent of participants were professional educators in mid- to late stages of their careers in education. In all three focus groups, participants had characteristics of "expert panels" within the educational community, providing a rich and diverse range of formally captured feedback from thirty-two participants.

Ulin, Robinson and Tolley (2015) recommend a minimum of two focus groups for a study. For the requirements of the current study, two focus groups would not have elicited the required depth of information and validation suggested by the DBR methodology (see Chapter 7). The study was more suited to having a minimum of three iterative development stages. This was due to the fact that the theoretical design of the instrument (Focus Group 1) required validation as a proof of concept (Focus Group 2) before proceeding to the extended development stage and trial of the CLEMS prototype in Focus Group 3 (The Design-Based Research Collective, 2003). The third focus group extended the time frame of the study, but resulted in greater clarity in addressing the research question.

The 3 focus groups were organised according to the following procedure.

1. Pre-focus group organisation and preparation

- A date and venue for the focus group was set in collaboration with the lead supervisor
- Advertising information in the form of emails and flyers were created
- The invitation process was discussed
- Participants were invited via email through inter-departmental networking coordinated by the lead study supervisor and via the personal network of the researcher.

Documents and resources for the focus group were sourced and created, including:

- Ethics consent forms for participants
- Complaints procedure forms for participants
- Focus Group presentation with instructions and overview
- Questionnaires/data capture sheets
- Supporting information to support the understanding of the research study context for participants (glossary, background information, graphics)

- Post Focus Group feedback sheet for participants to comment on Focus Group procedures

Information was also made available for potential participants for all focus groups at www.elearningdesignphd.com, a MOODLE Learning Management System (LMS) instance that was used as a repository for the information and forms required by participants, as well as providing ethics clearance information for the study.

2. Focus group management

Focus groups were run according to the following procedure on the day of the event:

- Participants were welcomed
- Participants were given consent forms to complete, as well as forms fulfilling other ethics requirements
- Participants completed and handed in consent forms
- Supporting documentation for the focus group was handed out to participants
- (questionnaires/data capture sheets, supporting information)
- A presentation was given to provide instructions, clarify issues, set the research study context, answer questions and provide a brief introduction to the focus group
- Participants were asked to respond to questionnaires/data capture sheets
- The researcher answered questions and clarified issues as the discussions proceeded
- At the conclusion of the focus group, participants were provided with post-focus group feedback forms to complete and hand in.

<u>3. Post-focus group process</u>

Information was managed according to the low risk research status protocols of the university, as follows:

- The data elicited from the focus groups was collated, coded and summarised for interpretation and analysis
- Raw information was stored as per university ethics requirements
- Information was validated through triangulation between focus group cycles and between emerging information and ongoing literature review
- Feld notes were recorded and graphics were created to represent emerging relationships between data sets and the findings literature review
- The gathered information was incorporated into the thesis body and appendices.

Appendix N: Focus Group 2: Summary of Raw Data

This appendix provides a summary of the raw data responses from the participants in Focus Group 2, titled Evaluating a proof of concept of CLEMS.

Date: 30/9/16
Venue: University of Adelaide, School of Education

Table N.1 Roles of participants in Focus Group 2

ROLE OF PARTICIPANTS	Number
Senior Lecturer	1
Academic (lecturer)	1
Academic (teacher)	1
Senior lecturer (academic)	1
Senior lecturer (course developer)	1
Senior Instructional Designer	1

Notes: This table indicates the key roles of participants, with secondary roles declared by participants indicated in parentheses.

Aims of Focus Group 2

The aims of Focus Group 2 were as follows:

1. Build on the information gathered in Focus Group 1 as the next stage in advancing the theoretical model of the instrument towards its realisation as a useable prototype.
2. Extend the findings of Focus Group 1 to propose both a format and functionalities of the instrument by asking experts to review and provide feedback on a paper-based proof of concept of the instrument.
3. Engage an expert panel to brainstorm the proposed proof of concept to comment on strengths and weaknesses in order to refine the model and inform the design of the software instrument.
4. Construct validation of the statements used in the instrument to elicit information from expert panel.

Coding of responses from Focus Group 2

The feedback responses from Focus Group 2 were coded in key categories in the same way as the responses from Focus Group 1. As the theme of the Focus Group was evaluating a proof of concept of CLEMS, the following coding system was used to classify responses from participants. The purpose of coding was to assist with the process of identifying higher level themes for organising responses. No quantitative techniques were applied to the numbers of codes collected, as they were used to identify and clarify thematic areas, as follows:

1. Theory (Th)

Responses relating to theoretical aspects of the instrument

2. Technical and Systemic (T&S)

Responses relating to technical functions of the instrument

3. Content and information (C&I)

Responses relating to content and information within the instrument

4. Teacher (T)

Responses relating to the role and functions of the teacher

5. Learner (L)

Responses relating to the role and functions of the learner

Summarised comments and feedback from participants FG 2:

The responses have been summarised below for each respondent, with a code assigned to each response according to the above code key. The coding represented themes for consideration in the development of the instrument. In other words, the responses are treated broadly as considerations in validating the proof of concept of the instrument. Where more than one code could be applied to a response, a single key code representing the most likely code has been assigned.

Where notes, bullet points or comments were disconnected or lacked clarity in the responses, these were interpreted in the context of the part of the form responded to by the participant. Themes in the responses of each individual participant are identified, with a final summary represented as a collation of all responses in terms of the usefulness of the instrument, as well as potential weaknesses and pitfalls of the instrument.

Responses by Participant 1 and Assigned Coding

1. What is knowledge? (epistemology). **(Th)**
2. The instrument offers potential for differentiated learning - great. Mediative–adaptive. **(Th)**
3. Learner rating: Does the learner see the results of the analysis of their heutagogical capabilities? Do they respond? What do they do with it? **(L)**
4. A limitation of the instrument is that it is most appropriate for identification of struggling novices, may miss the mark with those at higher levels of expertise. **(L)**
5. Consider if the analysis of strengths and weaknesses of the program is an absolute measurement. If it is like the Zone of Proximal Development, isn't there an optimal zone? i.e. if the program is not challenging enough a learner might get "strong" but not learn much (three levels: too easy, optimal, too hard) **(Th)**

Point 5 above aligns with the findings of Doube (2007).

Summary of Responses by Participant 1

This participant validated the presented functions of the instrument as suitable for information-gathering and reporting. The instrument was noted to offer potential for differentiated learning, but may be limited to use for identifying struggling novices. This suggests the need to be open to alternative information sources that may expand and improve the cognitive load theoretical framework.

It is worth considering the benefits (or otherwise) of letting learners have access to analysis of their own strengths and weaknesses. Also, consider how the optimal zone of learning will be achieved for learners and if learning programs are rated against an absolute or relative level. This respondent focused key responses around Vygotsky's theory of social learning to represent the learning process.

Responses by Participant 2 and Assigned Coding

a. ‘Split-attention effect is also applicable in teaching/learning’. **(Th)**
b. ‘Usefulness of the instrument could be for: assessment, feedback and reflective practice’. **(T)**
c. ‘Could the use of the instrument be broadened to: policy, curriculum, ‘teacher’, standards from other bodies’. **(T&S)**
d. ‘People can learn from it’. **(T&S)**
e. ‘Organic use of technology’. **(T&S)**
f. ‘Load is the mental effort required to learn’. **(Th)**
g. ‘How much does the novice’s personal ontology affect their learning?’ **(L)**
h. ‘Resilient people learn better/worse than anxious people?’ **(L)**
i. ‘Creative/divergent thinkers vs. autistic [?] procedural learners’. **(L)**

j. ‘Novices have low heutagogical skills’. **(L)**

k. ‘Schemas represent chunks of learning’. **(Th)**

l. ‘Intrinsic load is a base line of learning e.g. an alphabet, periodic table of learning’. **(Th)**

m. ‘Problem-solving may not equal learning, but if the problem is beyond the Zone of Proximal Development of the learner, then this makes sense’. **(Th)**

n. ‘Expert: recognition of schema - or intuit a problem, problem solving may not equal learning for novices’. **(L)**

o. ‘I don’t think it can be any problem at all. It may depend on the learner who brings to the learning their own discursive subjectivity. Otherwise the learner event a novice is ‘tabula rasa''- it doesn’t follow to me. No one is tabula rasa’. **(L)**

p. ‘How can you focus on process when process is defined in part by the thing you want learned? e.g. I learn music differently from the way I learn knitting’. **(Th)**

q. ‘Video offers the ability to repeat - asynchronous review’. **(T)**

r. ‘Metacognitive skills and feedback’. **(T)**

s. ‘Level of ability to problem solve represents the highest level of schema development’. **(Th)**

t. ‘Some PhDs are crappy teachers: an expert learner is not an expert teacher’. **(T)**

u. ‘Show strengths and weaknesses for a student in a program’. **(L)**

v. ‘Data can be mined’. **(T&S)**

w. ‘Diagnosing learner disabilities? Or need for support e.g. a psychologist. Diagnostic feature of instrument means that additional support can be set for a school student who may have learning needs’. **(T&S)**

x. ‘Learner with needs can be sent to a secondary teaching team’. **(L)**

y. ‘pedagogic strategy needs to place learners in their Zone of Proximal development’ **(Th)**

z. ‘The instrument could be used for one student or many’. **(T&S)**

Summary of Responses by Participant 2

This participant demonstrated clear understanding of CLT principles and practices and validated the presented functions of the instrument as suitable for information-gathering and reporting. It was noted that the usefulness of the instrument could be for: assessment, feedback and reflective practice, as well as for broader applications such as informing policy, developing curriculum or setting standards.

Additional consideration in the instrument’s design could include factors such as learner resilience, metacognitive capability, teaching methods being aligned with learner preferences, aligning learning with the learner’s zone of proximal development, and using the instrument to determine levels of further personalised support for learners. The instrument was noted to have the potential for data mining of information. Similar to respondent 1, this respondent framed responses around Vygotsky’s theory of social learning to represent the learning process.

Responses by Participant 3 and Assigned Coding

a. ‘Slide is a huge visual load of text’. **(Th)**
b. ‘Have you looked at Harvard’s Project Zero 'Making thinking visible’ (Ritchhart and Perkins, 2008)?’ **(Th)**
c. ‘Learners flounder without intervention’. **(L)**
d. ‘Cognitive load is the mental effort required to engage in a task’. **(Th)**
e. ‘Intrinsic load: irreducible weight of learning’. **(Th)**
f. ‘Experts use schemas that have already been built, but novices use means–ends analysis’.

(Th)

g. ‘Sweller’s (1988) Problem solving does not result in learning. Cognitive load theory: reorganise information to automate it e.g. 100 000 schemas in grandmaster chess - call on it as a chunk’. **(Th)**

h. ‘Current ideas on LTM (Long-Term Memory) is that it does not stabilise/consolidate for more than 10 years. If ‘Learning in cognitive load theory is established in LTM’ this may need to change to be useful’. **(Th)**

i. ‘Would it be helpful to connect to Threshold Concepts (Meyer & Land, 2000, 2003, 2005, 2006). This could be a way of honing in to the most critical aspects of what must be focused on’. **(Th)**

j. ‘This tool is just another way of gathering evidence to formulate individual learning plan. Individual learning plan for students is not a new idea but impractical where inefficiently resourced’. **(T&S)**

k. ‘What is ‘program of learning?” Individual learners may be at different levels of learning in relation to various elements of that program. The longer the program the more elements’. **(L)**

l. ‘Resourcing? With large classes % sampling or rather than individual learning plans could be used for modifying learning program for cohort characteristics rather than individuals’. **(T&S).**

<u>Summary of Responses by Participant 3</u>

This participant demonstrated a deep understanding of cognitive load theory and validated the presented functions of the instrument as suitable for information-gathering and reporting. These responses provided references to research that expand the basis for the instrument by including additional concepts such as Visible Learning, Threshold Concepts and awareness by teachers of learners who are floundering (Clark, 2013, pp. 6, 73, 141) in their learning progress due to learning barriers (see Learning Barrier).

The instrument was observed to be another method of devising individualised education plans, but cautioned regarding practicalities of resourcing it. Due to potential resourcing issues, it was noted that the instrument may be more suitable for cohorts than for individuals. This also reinforces the notion that the instrument may contain the capabilities for determining both individual and cohort needs, where the teacher can select its appropriate application.

<u>Responses by Participant 4 and Assigned Coding</u>

a. ‘This is one theory, but others may also contribute to understanding what progress may be going on for any individual learner’. **(Th)**
b. ‘Metacognition: was research controlled for capacity to articulate metacognition? **(Th)**
c. Does supported problem solving allow for self-supported i.e. highly reflective learners?’ **(L)**
d. ‘Mediative and adaptive. Mediative (needs teacher mediation); adaptive adjusted to individual learners’. **(T)**
e. ‘Match strategy to where learner is at’. **(L)**
f. ‘Learning program able to be variable to meet learner where they are at - at that point in time’. **(L)**
g. ‘Flexibility - time, location, place and format’. **(T&S)**
h. ‘Change the word ‘like’ in statements as it is a value-laden expression’. **(C&I)**
i. ‘If a learner can't articulate or doesn't have an answer, teacher mediation is required’. **(L)**

j. ‘How aware of process is the learner of their ways of operating and why?’ **(L)**

k. ‘Effective processes may not be consciously considered’. **(L)**

l. ‘Experts - if they go to highest order schema in their LTM they may be unsuitable to guide novices if they can’t deconstruct that schema and go back to the level the student is at’. **(Th)**

m. ‘Rapid evaluation is highly dependent on reliability, validity and availability’. **(Th)**

n. ‘Evaluation or tests? (pre- and post-tests). Which is meant?’ **(C&I)**

o. ‘Some learning is not readily evident through a test’. **(L)**

Summary of Responses by Participant 4

This participant validated the presented functions of the instrument as suitable for information-gathering and reporting. This respondent pointed out that CLT is only one theory on which to base the instrument, and others may also be valid. This points to the need to provide a strong justification for using CLT in this study. In this study, the argument for the use of CLT has developed from its historical research foundations in cognition, as well as its use of RCTs to validate its strategies. However, this does not preclude the development of similar instruments that are based on other research foundations. Moreover, the methodology and methods of the current study have been documented in a format which would make the study reproducible with different theoretical paradigms and focus groups, or alternatively including combined perspectives from multiple theoretical perspectives (Tuovinen, 2005). Additional considerations in the design of the instrument include adaptability to learner achievement levels, the need for mediation by the teacher, as well as the heutagogical factor of self-reflectivity of learners. Learners with high levels schema of development may not be suitable for guiding novices as they may not have deconstructed their own learning sufficiently to understand underpinning processes.

Responses by Participant 5 and 6 (Combined) and Assigned Coding

a. ‘Heutagogical (self-directed); pedagogical (teacher) considerations’. **(Th)**

b. ‘Instructional design considerations’. **(Th)**

c. ‘Germane cognitive load relates to automation of schemas, building of schemas’. **(Th)**

d. ‘Automation includes call-up of both information and rules’. **(Th)**

e. ‘Will an intervention be set for each student**? Does this mean every student may have a different version of the program? Or have a different intervention? Does this make much more work for the teacher?’ **(T)**

f. ‘Will the Learner/Program analysis be evaluated for purpose of overall improvement of course? or improvements student by student?’ **(T&S)**

g. ‘Can this instrument be used to 'stream' students?’ **(T&S)**

h. ‘This is good (referring to analysing relative strengths and weaknesses of program)’. **C&I)**

i. ‘Will the description of the intervention be added to the overall bank of information?’ **(C&I)**

*The individualisation of learning is a key issue in higher education. Halabi, Tuovinen & Smyrnios (2000) demonstrate the possibility of providing computer-based learning materials for differentiated learners; Mayer (2005) provides substantial collated research that supports the individualisation of learning in multimedia environments; Kalyuga (2007, 2009a, 2209b) provides an extensive rationalisation for adaptive learning based on the model of human cognitive architecture posited by CLT.

<u>Summary of responses by participants 5 & 6 (combined)</u>

Participants validated the presented functions of the instrument as suitable for information-gathering and reporting. Respondents emphasised heutagogical functions, as well as the functions of different cognitive loads, in particular the goal of achieving schema automation through increased germane cognitive load.

Consideration was given to the use of the instrument for individual learners vs. cohort and whether the instrument could be used to stream students. The analysis of strengths and weaknesses of learning programs was seen as a positive characteristic of the instrument.

Overall summary of responses by participants

A broad variety of responses was provided by participants for consideration in the development of the instrument. All participants validated the format and functions of the instrument as presented in the Focus Group information sheets. The range of responses in terms of coding categories were as follows:

1. Theory (Th): 27 responses
2. Technical and System (T&S): 11
3. Content and information (C&I): 4
4. Teacher (T): 6
5. Learner (L): 19

Total: 67 responses

In summary, responses provided significant validation of the theoretical framework of the instrument and learner-centric processes (cf. APA, 1997–Learner-centered psychological principles). Moreover, additional functions were noted and recommended and numerous useful questions were raised for consideration, including use of the instrument at a systems level for data mining and for informing educational policy.

The next section provides an overview and summary of the post focus group evaluation by participants.

Post-Focus Group 2 evaluation by participants

Date: 30 September 2016

Post Focus Group Evaluation - David Isaacson's PhD Focus Group

Please rate each point on a scale of 1–5, where 1=Low and 5=High

Table N.2 Post-Focus Group 2 evaluation by participants

Number	Evaluation statement	Rating by 6 Respondents and Summary of Comments (*=no answer provided)
1	The venue was suitable for the focus group	5, 5, 4, 5, 4, 5 Average: 4.6
2	The catering was as expected	5, 5, 5, 5, 5, 5 Average: 5
3	The purpose of the focus group was clearly explained	4, 4, 4, 5, 3,* Average: 4.3
4	Housekeeping/safety/conditions were clearly explained	4, 5, 5, 4, 4, 4 Average: 4.3
5	Ethics forms and rights of participants were clearly explained	4, 5, 5, 5, 4, 5 Average: 4.7
6	The presentation sequence of the instrument was clear	4, 3, 3, 4, 3, 4 Average: 3.5
7	I learned some new things about Cognitive Load Theory from this focus group	4, 5, 4, 5, 5, 5 Average: 4.7
8	I learned some new things about technology in education from this focus group	4, 3, 2, 2, 3, 2 Average: 2.7
9	This instrument would be useful to me in my educational context	4, *, 3, 2, *, 4 Average: 3.25
10	This focus group would have been better if ...	‘More time to challenge (tease out) cognitive load theory’.

		'One slide had high visual load'. 'Bit less theory and focus on application and testing'. '... we could see the instrument: but it's still in development, yes?' 'Didn't clearly understand what we were asked to do'. 'I'm still not convinced it could be used for large classes'. 'Probably longer, with a break'.

Observations from Post Focus Group 2 Evaluation

Summary:

The feedback from the post focus group evaluation revealed a strong base of understanding of technology in education. Some participants demonstrated an in-depth knowledge of CLT and its application, while others focused their practice on Social Learning Theory. Overall, the functions of the instrument were validated as suitable for gathering the information from learners and teachers, as well as reporting on learner progress through analytics.

In terms of the usefulness of the instrument, the lower rating than Focus Group 1 may be explained by the complex nature of the instrument attempting to be conveyed through a paper-based proof of concept, where participants wanted 'to see the instrument'. As functions of the instrument were portrayed on separate pages, this could have imposed a high cognitive load on participants with low knowledge of CLT in the form of split-attention; to mitigate this, an online version with hyperlinks* could have communicated the concepts and interface more clearly.

On reflection, it would have been fairer to the participants to provide a useable prototype, however basic, to supplement the multiple pages presented in this focus group.

Notwithstanding this limitation, a broad variety of considered feedback was provided by participants for informing the next stage of development of the instrument.

*[Hyperlinks may cause split-attention for some learners and therefore this factor needs to be taken into consideration in designing learning interventions (Sweller, Ayres & Kalyuga, 2011, pp. 111–128)]

Focus Group 2: Conclusion and next steps in the research process

This Focus Group validated the proof of concept of the instrument at both a functional level (input fields for learner and teacher; analytic reporting capabilities) and content level (CLT effects; heutagogical effects). This represented a significant step in the development cycle, since it was the first visualisation of the theoretical model in terms of user experience. Additional theoretical frameworks were suggested as being valid as the main focus of the instrument, including Vygotsky's (1930, 1978) Social Learning Theory and Meyer and Land's (2000, 2003) Threshold Concept Theory implying that CLT could be combined with one of these theories as a future research direction. In terms of pursuing these alternative research directions, the current study includes documentation of the research methodology, methods and materials, thereby providing a research process for investigating alternative theoretical frameworks by future researchers. The rationale for the selection of CLT as the selected framework for this study is based on its evidence-based research framework using RCTs and its unified model of human cognitive architecture as standards for evaluating the quality of learning design (see Chapters 1–6). In addition, the expertise model of learning assumed for the instrument provides a substantially validated process for evaluating the acquisition of expertise by learners, which aligns with the concept of schema formation and automation posited in CLT research (see Automation)(Sweller, Ayres & Kalyuga, 2011).

The expanded use of the instrument for data-mining and informing policy was noted as a valued affirmation of its systemic capabilities. Overall, the monitoring of the learner's progress in terms of both domain knowledge and heutagogical capability was validated, as was the use of the instrument for both individual and cohort evaluation. Moreover, the extensibility of the instrument to include additional heutagogical factors such as learner resilience and metacognitive skills was noted.

This Focus Group had a smaller number of participants than Focus Group 1. However, the high calibre of participants in terms of qualifications and experience elicited a rich set of responses to the format and content of the instrument, as well as theoretical considerations and future uses of the instrument. The presentation of the proof of concept instrument was paper-based, which is acknowledged as a potential weakness that could have been more clearly presented in an online environment. However, participants were generally able to overcome this limitation and provide a broad range of useful feedback in terms of the goal of the Focus Group.

In summary, sufficient information was provided by participants to fulfil the goal of the focus group and proceed to the next research iteration. The collated information from this focus group, which was built on the feedback from Focus Group 1, enabled a detailed functional specification to be developed as a blueprint for the prototype software instrument. The completion of Focus Group 2 initiated the third iterative research cycle.

Appendix O: Focus Group 3: Summary of Raw Data

This appendix provides a summary of the raw data responses from the participants in Focus Group 3, titled Evaluating CLEMS. Details of the focus group are in Table O.1 below.

Date: 7 November 2017

Venue: University of Adelaide, Faculty of Education

Table O.1 Primary and secondary roles of the 11 participants in Focus Group 3

NUMBER OF PARTICIPANTS	11
Academic Researcher	3
Administrator	1
Manager	2 (1)
Lecturer/Trainer	3 (5)
Instructional Designer	1 (2)
Student	1

Note: This table indicates the key roles of participants, with secondary roles declared by participants indicated in brackets e.g. under Manager, two participants declared Manager as their primary role and one participant declared Manager as their secondary role, etc.

Key for coding of responses by participants in this Focus Group.

This coding system was also used in Focus Groups 1 and 2. The feedback responses from Focus Group 2 were coded in key categories. As the theme of the Focus Group was Evaluating a Proof of Concept of CLEMS, the following coding system was used to classify responses from participants. The purpose of coding was to assist with the process of identifying higher-level themes for organising responses. No quantitative techniques were applied to the numbers of codes collected, as they were used to identify and clarify thematic areas, as follows:

1. Theory (Th)

Responses relating to theoretical aspects of the instrument

2. Technical and Systemic (T&S)

Responses relating to technical functions of the instrument

3. Content and information (C&I)

Responses relating to content and information within the instrument

4. Teacher (T)

Responses relating to the role and functions of the teacher

5. Learner (L)

Responses relating to the role and functions of the learner

Table O.2 Average Ratings of Current Features (on a scale of 1–5)

	Parameter	Scores and Average Rating (to 1 decimal point)
1	Systems approach to learning design evaluation	Individual ratings by 11 participants (in order): 3, 4, 5, 5, 3, 5, 4, 4, 5, 5, 4 Tallied scores divided by 11 participants: 47/11 Average of all responses: **4.3**
2	Cloud-based software instrument	Individual ratings by 11 participants (in order): 1, 5, 5, 5, 1, 5, 4, 5, 5, 4, 5 Tallied scores divided by 11 participants: 45/11 Average of all responses: **4.1**
3	Iterative reporting to reflect continuous improvement	Individual ratings by 11 participants (in order): 4, 5, 5, 5, 4, 5, 5, 4, 5, 4, 4 Tallied scores divided by 11 participants: 50/11 Average of all responses: 4.5
4	Providing visualised reports	Individual ratings by 11 participants (in order): 2, 5, 4, 5, 5, 5, 5, 5, 5, 5, 5 Tallied scores divided by 11 participants: 51/11 Average of all responses: **4.6**
5	Teacher-controlled	Individual ratings by 11 participants (in order): 4, 5, 4, 5, 3, 5, 4, 5, 4, 5, 5

		Tallied scores divided by 11 participants: 49/11 Average of all responses: **4.4**
6	Rapidly deployable	Individual ratings by 11 participants (in order): 4, 5, 5, 5, 2, 5, 5, 4, 5, 5, 4 Tallied scores divided by 11 participants: 49/11 Average of all responses: **4.5**
7	Educative (informative about educational theory and practice)	Individual ratings by 11 participants (in order): 5, 5, 5, 5, 4, 5, 5, 4, 5, 5, 4 Tallied scores divided by 11 participants: 52/11 Average of all responses: 4.7
8	Providing feedback on GENERAL level of evidence-based interventions in courses	Individual ratings by 11 participants (in order): 3, 5, 4, 5, 4, 5, 5, 3, 5, 5, 4 Tallied scores divided by 11 participants: 48/11 Average of all responses: 4.4
9	Providing feedback on SPECIFIC level of evidence-based interventions in courses for individual students	Individual ratings by 11 participants (in order): 5, 4, 4, 5, 3, 5, 5, 3, 4, 5, 5 Tallied scores divided by 11 participants: 48/11 Average of all responses: 4.4
10	Facilitates creation of Personalised/Adaptive interventions for learners	Individual ratings by 11 participants (in order): 2, 5, 4, 5, 3, 5, 5, 3, 4, 5, 5 Tallied scores divided by 11 participants: 46/11 Average of all responses: 4.2
11	In-built Dynamic Knowledge Database (DKD) to provide information for creating interventions	Individual ratings by 11 participants (in order): 1, 5, 5, 5, 3, 5, 5, 4, 5, 5, 5 Tallied scores divided by 11 participants: 48/11 Average of all responses: 4.4
12	Long-term storage of evaluation data in the system for future use	Individual ratings by 11 participants (in order): 4, 5, 3, 5, 4, 3, 5, 4, 3, 4, 5 Tallied scores divided by 11 participants: 45/11 Average of all responses: 4.1
13	Extensible (capability of being modified or updated	Individual ratings by 11 participants (in order): 4, 5, 3, 5, 3, 5, 5, 3, 5, 5, 4

	with new research/questions/ statements	Tallied scores divided by 11 participants: 48/11 Average of all responses: 4/4
14	Usefulness as a training or professional development tool for educators	Individual ratings by 11 participants (in order): 4, 5, 4, 5, 4, 5, 5, 3, 5, 5, 5 Tallied scores divided by 11 participants: 51/11 Average of all responses: 4.6
15	Improving quality of courses in terms of evidence-based content	Individual ratings by 11 participants (in order): 4, 5, 4, 5, 3, 5, 5, 3, 5, 5, 5 Tallied scores divided by 11 participants: 49/11 Average of all responses: 4.4
16	Improving quality of learning experiences for learners	Individual ratings by 11 participants (in order): 1, 4, 5, 5, 3, 5, 5, 3, 5, 4, 4 Tallied scores divided by 11 participants: 44/11 Average of all responses: 4.0
17	Cognitive Load Theory as an Evaluation Model	Individual ratings by 11 participants (in order): 5, 5, 5, 5, 4, 5, 4, 4, 5, 5, 4 Tallied scores divided by 11 participants: 51/1 Average of all responses: 4.6
18	Interface bland – needs to be improved visually	3=3/1=**3**
19	Interface – needs embedded help with action options	3=3/1=**3**

Table O.3 Additional comments by participants in Focus Group 3

Additional Comments with coding	
1	'Probably requires some additional background knowledge with cognitive load theory on behalf of instructors and students'. **(C&I)**
2	'Interface: consider multi-panel window so you can see all data concurrently without having to open separate windows'. **(T&S)** The user interface will require design according to principles of cognitive load theory e.g. avoidance of the split-attention effect and possible navigational aids and colour coding to draw the user's attention to the appropriate on-screen information. 'Allow 'clicking' on risk level (e.g. 'H') to add intervention for that metric (or open the dialog box), instead of going to a separate window'. **(T&S)** 'Auto-add "specific guidelines" button could be added instead of having to copy-paste'. **(T&S)** 'Add a pre-quiz so students' pre-course abilities can be automatically and objectively added'. **(C&I)**
3	'A very practical process driven tool to facilitate course evaluation'. **(T&S)** 'I think the ability to link into an LMS will be very important to see it working across large institutions'. **(T&S)**
4	'Not clear how the system can be programmed and adapted by users'. **(T&S)**
5	'I think this would be useful for academic staff to monitor and visualise the impact the course is having on student learning outcomes'. **(T)** 'Quite often the questions are asked and increasingly with more and more courses going online I believe there will be a need to monitor data and the progress of the course as we are experimenting with different learning designs'. **(T&S)**
6	'Some questions may need to be explained by giving specific examples in context i.e. need to explain jargon'. **(C&I)** 'Aggregate data would be useful'. **(T&S)** 'Data that lay outside pre-defined parameters (e.g. very low or very high values) is identified so interventions can be designed'. **(T&S)** 'For me (educative aspect) is key and gives the tool the ability to upskill the educator in evidence-based practice'. **(C&I)** 'May be time consuming if the aim is to create one intervention for each student'. **(T)** The individualisation of learner pathways is well-supported in the literature of cognitive load theory e.g. Mayer (2005) and Kalyuga (2007).

	'Aggregate student data would be useful particularly with large courses'. **(T&S)**
7	'Having peer-assessed component has potential to reduce inherent issues of self-evaluation'. **(L)** 'How to ensure comparing 'apples with apple'. Doesn't matter so much when evaluating within a course, but if using more broadly, this could create problems?' **(T)** 'Does instrument allow evaluation of assessment? or if not, can a similar instrument do this?' **(T&S)** 'Does it integrate student outcomes to compare with evaluations?' **(T&S)** 'How to minimise self-evaluation difficulties students may face? e.g. over or under evaluation'. **(L)**
8	'A very useful framework for teachers to evaluate a subject/course against cognitive load theory'. **(T)** 'Assessments are subjective but that's ok'. **(C&I)** 'The framework to assist reflection and continuous improvement of learning by teachers is valuable'. **(T)**
9	'I think this could be really useful to training organisations too, not just educational institutions'. **(L)**
10	'Will need to explain some terminology (e.g. goal-free problems)'. **(C&I)** 'Could use for online courses run by [organisations'.**(L)** 'Not sure about 'risk''- negative? Rephrase as level and invert High and Low?' **(C&I)**
11	'Looks like the instrument is self-calibrating'. **(T&S)** 'It would be useful if the instrument can capture individual students' attitudes/perceptions of a particular course'. **(L)** 'Useful to know how many students the system can cater for'. **(T&S)** 'Perhaps including students' qualitative (open response) feedback would also be useful'. **(L)**

Key: Participants rated the necessity for characteristics and parameters of the instrument on a scale of 0-5, where 0 represented low and 5 represented high necessity.

Table O.4 Participant ratings of future characteristics of the instrument

Ratings and averages for Possible Future Developments of the Instrument [CLEMS] (Scale of 1–5)		
	Parameter	**Average Rating**
1	Available as an app for mobile devices	Individual ratings by 11 participants (in order): 3, 4, 4, 5, 5 ,5, 3, 3, 4, 1, 5 Tallied scores divided by 11 participants: 42/11 Average of all responses: **3.8**
2	Available within a Learning Management System	Individual ratings by 11 participants (in order): 5, 3, 5, 5, 5, 5, 5, 5, 5, 5, 5 Tallied scores divided by 11 participants: 53/11 Average of all responses: **4.8**
3	Links to social media e.g. for reporting improvements in courses	Individual ratings by 11 participants (in order): 1, 1, 2, 5, 5, 3, 3, 3, 2, 2, 4 Tallied scores divided by 11 participants: 31/11 Average of all responses: **2.8**
4	Include different forms of data visualisation or graphical outputs	Individual ratings by 11 participants (in order): 4, 2, 3, 5, 5, 4, 4, 3, 4, 2, 5 Tallied scores divided by 11 participants: 41/11 Average of all responses: **3.72**
5	Printed reports (e.g. .pdfs or emails)	Individual ratings by 11 participants (in order): 4, 4, 5, 5, 5, 5, 4, 4, 2, 5, 5 Tallied scores divided by 11 participants: 48/11 Average of all responses: **4.4**
6	Increased number of evaluation iterations	Individual ratings by 11 participants (in order): 4, 4, 2, 5, 4, 4, 4, 3, 5, 5, 5 Tallied scores divided by 11 participants: 45/11 Average of all responses: **4.1**
7	Capability for teachers to select questions/statements in forms	Individual ratings by 11 participants (in order): 5, 2, 5, 5, 5, 4, 5, 4, 5, 5, 5 Tallied scores divided by 11 participants: 50/11

		Average of all responses: **4.5**
8	Links to training resources in the specific parameters	Individual ratings by 11 participants (in order): Tallied scores divided by 11 participants: 49/11 Average of all responses: **4.5**
9	Sharing and rating of specific practices and pedagogies amongst teachers	Individual ratings by 11 participants (in order): 5, 4, 4, 5, 4, 5, 5, 3, 5, 5, 4 Tallied scores divided by 11 participants: 46/11 Average of all responses: **4.2**
10	Comparing reports between classes, departments, institutions	Individual ratings by 11 participants (in order): 2, 5, 4, 5, 5, 5, 4, 3, 3, 5, 5 Tallied scores divided by 11 participants: 46/11 Average of all responses:4.2
11	Ability to determine at any point the level of evidence-based practices in a department or institution	Individual ratings by 11 participants (in order): 4, 5, 3, 5, 4, 5, 5, 3, 4, 5, 4 Tallied scores divided by 11 participants: 47/11 Average of all responses: **4.3**

Post-Focus Group 3 Evaluation - Collation of responses with summary of comments.

Date: 7 November 2017

Evaluate a software learning design evaluation tool (CLEMS) based on Cognitive Load Theory

Table O.5 Focus group rating questionnaire and responses

Please rate the following items for the Focus Group	Your Rating: 1 = Low, 5 = High) Circle Applicable
The focus group was well organised	4, 3, 5, 4, 5, 4, 4, 4, 4, 3, 3
The procedures of the focus group were clearly explained	5, 3, 5, 5, 4, 5, 5, 4, 4, 4, 4
My rights as a participant were explained to me e.g. my right to withdraw at any point without prejudice	5, 4, 5, 5, 1, 5, 5, 4, 4, 4, 3
Safety procedures (e.g. emergency evacuation) were explained to me	4, 2, 5, 1, 1, n/a, 4, 4, 5, 3, 5
I understood what was expected of me through clear written and verbal instructions	5, 4, 5, 4, 4, 5, 5, 4, 4, 5, 5, 4
Sufficient time was provided to review the instrument and provide feedback	5, 4, 5, 3, 5, 5, 5, 4, 4, 5, 4
I learned about Cognitive Load Theory	3,4,5,3,1,5,3,3,4,5,4
[I] my knowledge of educational theory was increased.	3, 3, 5, 3, 1, 5, 3, 3, 4, 5, 4
I had the opportunity to contribute ideas and feedback verbal and/or in writing	5, 4, 5, 5, 3, 5, 5, 4, 4, 5, 5
The food and refreshments were appropriate for the event and catered for my needs	5, 4, n/a, n/a, 3, *, 5, 4, n/a, n/a, 4
The technology was appropriate for trialling the software	5, 4, 5, *, 5, 1, 3, n/a, 3, 5, 3
Appropriate technical support was available during the focus group	5, 2, 5, 1, 3, 1, 2, 2, 3, *, 1

Note. n/a reflects n/a written by participant; * denotes non-rated statement

Summary of comments from participants.

- ‘More time on cognitive load theory? Might have helped convince those who are slightly less familiar’.
- ‘There were some tech access issues, but it did not make the software less adequately demonstrated’.
- ‘We were not able to trial due to technological software issues but assume would have been okay without this problem; were able to watch demonstration.’

- ‘Apart from the software glitches – all the session was excellent. I missed out on OHS information being slightly late.’
- ‘Pre-testing [required].’
- ‘I enjoyed your presentation David – thank you and good luck!’
- ‘The potential of the program/system for educational use was quite evident. This is an excellent initiative.’
- ‘Thank you for the opportunity, fabulous to be involved. The tool is excellent and I can see great use for it in the tertiary sector (the computer suite was fine, but the software technology didn’t work)’.
- ‘Thank you for the opportunity – I wish you well in the development of this useful tool and with your PhD’.

Thank you for participating in this focus group

David Isaacson, Nov. 7, 2017

PhD Student (Primary Researcher)

Appendix P: Principles for use of CLT Effects and Strategies in CLEMS

This appendix contains a summary of the organisational principles for using pedagogical effects and strategies arising from CLT in CLEMS. In addition, it includes examples of questions for teachers to use in course evaluations for inclusion in the CLEMS DKD. It was noted in Chapter 1 that the body of research findings arising from CLT exist in disparate sources such as journal articles and other publications and have not yet been collated into a convenient catalogue or single source of truth for use by educators.

A key contribution of this study is therefore the gathering, collation and organisation of the effects and strategies arising from CLT for inclusion within CLEMS as a single, accessible source. This body of knowledge is included in the Dynamic Knowledge Database (DKD) of CLEMS with additional information to support teachers in designing NOE learning interventions. Additionally, the DKD may be modified or updated by including emergent effects from CLT or removing redundant information as part of its ongoing continuous improvement process.

Using CLEMS, educators will be able to search for the specific CLT effects and strategies that increase the level of evidence-based practices in their courses. In addition, these effects and strategies will underpin the NOEs that teachers formulate for individual learners. CLEMS facilitates the inclusion of increased evidence-based practices in the form of CLT strategies at two levels: first, the increased level of CLT strategies in courses, programs or teaching materials that are evaluated without reference to individual learners; secondly, the formulation of Nodes of Expertise (NOEs) for individual learners, where NOEs are goals in the form of targeted clusters of complex knowledge elements designed to advance learners through learning barriers to the next level of expertise. NOEs also suggest that the design of learning goes beyond curriculum-driven knowledge to the way that experts in the specific domain think about using and applying the knowledge, therefore favouring the derivation of learning content from cognitive task analysis (CTA) rather than behaviourally-based task analysis which may not necessarily include specific instructions on how experts conceive, think and apply the knowledge.

The effects and strategies are organised according to their pedagogical application. However, the organisation of effects and strategies into different categories does not imply that learning is not holistic, but are expressed as integrated NOEs.

Category 1: Governing Principles

a. Schema building vs. means–ends analysis

Application of this principle: for novices, learning should be structured to avoid the default process of means–ends analysis and focus on the formation and automation of schemas through the process of direct and explicit building of the learner's content knowledge. The rationale for this process is that automated schemas lighten the burden on the processing capacities of working memory as well as trigger the long-term working memory (LTWM) effect, where automated schemas serve the executive function of bypassing the inherent limitations of working memory.

b. Expertise Reversal Effect

Application of this principle: learning interventions need to be dynamically adjusted to align with the relative level of expertise of the learner to ensure that learning interventions advance learning and do not exert a neutral or negative learning effect. The dynamic adjustment of knowledge levels within courses may occur through different strategies e.g. the DC–NOE–VC process, signalling and cueing within multimedia environments, pathways through content that are determined by learner outcomes or scores in learning management systems or learner choice and control where learners have sufficient prior knowledge and capability to make these choices.

c. Prior knowledge

Application of this principle: the state of development of the learner's long-term memory schemas, in which is nested the entire knowledge store of the learner, is the most critical factor in advancing learning towards higher levels of expertise. The quantity and quality of schemas impact both the quality and rate of new learning. A more detailed model of the quality of schemas and schema development is contributed through this study at the following seven levels:

1. unformed
2. incompletely formed
3. erroneously formed
4. formed but not automated
5. formed and automated for near transfer
6. formed and automated for far transfer
7. expert application of formed *and* automated prior knowledge schemas i.e. learner has advanced understanding of the knowledge domain, a high level of heutagogical capability, situation awareness, as well as independence and creativity in applying principles to anisomorphic problems in authentic work contexts.

The expanded view of levels of prior knowledge builds of the research of Chi (2000, p. 161) who advanced the pedagogical idea of repairing knowledge schemas as one of the goals of the self-explanation effect. The notion of schema repair aligns with conceptual changes in the thinking processes of the learners in terms of correcting biases, prejudices, fixed mindsets and *einstellung* or mental set, misconceptions or alternative conceptions (Burgoon, Heddle, & Duran, 2010; Dweck, 1998; Luchins, 1942; Méheut, 2012; Nguyen, 2015; Sweller, 1980; Sweller & Gee, 1978). The process of schema repair also aligns with the heutagogical capability of learners by facilitating higher levels of self-monitoring, self-regulation and metacognitive capability (Chick, Karis & Kernahan, 2009). The seven-stage model using descriptors of schemas in various states of disrepair (or functioning) present an articulated model of the repair of prior knowledge schemas (see Section 10.5) that teachers can use a targeted diagnostic tool for identifying barriers to learning.. Further research is required to validate or modify this model experimentally within the educational community.

d. Time to mastery

Application of this principle: as each learner has unique prior knowledge profiles indicating different states of schematic development, the time taken for individual learners to advance to the next level of expertise will depend on this profile (Bloom, 1968, 1984; see Narrow limits of change principle). In delivering learning programs within a personalised and learner-centric model, appropriate time should be allocated to the formation and automation of schemas as represented by a mastery or expertise level of attainment within the knowledge domain. While curriculum delivery may operate within time constraints (e.g. terms, semesters or years), creative learning delivery methods need to be devised to ensure that learners have the time and support to automate schemas and that schema development is not truncated or cut short before full automation is attained. The use of sprints (intensive, supportive periods of learning with expert support) and jogs (less intensive learning periods, with lower levels of guidance) are learning environments of greater or lesser intensity that can support schema development where time constraints exist. Sprints and jogs may represent a format for varying spaced and massed learning, with time gaps for rest periods between sprints and jogs as well as within them (Chen & Kalyuga, 2020).

e. Learning

Application of this principle: within the CLT model: learning is defined as the formation and automation of schemas, as evidenced by persistent or permanent changes to long-term memory structures. At a pedagogical level, the evidence of learning as defined by schema automation is the learner’s immediate recognition of problem types or categories in a knowledge domain, as well the learner’s immediate recognition of the principles governing their resolution. The application of governing principles will vary according to the learner’s current level within the content curriculum (e.g. novice, advanced beginner, etc.) and may be applied to problems of greater or lesser complexity for near or far transfer. Where the far transfer of knowledge is set as a learning goal, a learner with advanced near transfer skills my become a novice again and will require schemas to be formed and automated under direct and explicit guidance of the teacher e.g. through the use of worked and faded examples or through signalling and cueing withing the content to indicate how principles may be applied in far transfer contexts.

Category 2: Content Formatting Principles

a. Use of Cognitive Load Theory Effects and Strategies:

Application of this principle: this principle governs the arrangement of media in text-based or online (multimedia) courses. Effects include practice problems formatted as goal-free problems; practice problems formatted as worked examples (or worked examples, completion problems and traditional problem solving tasks). See Full Examples–See Sweller, Ayres and Kalyuga (2011, p. 106) for reference to full problem solving; media content formatted to eliminate split-attention by integration of spatial and temporal content and removal of redundant materials that do not contribute directly to schema formation and automation.

b. Cognitive Theory of Multimedia Learning (CTML) Effects

Application of this principle: CTML consists of the application of guidelines for strengthening learning in multimedia environments. The intention of this category is to implement the specific strategies relating to the arrangement of multimedia elements, with the purpose of strengthening learning through schema formation and automation.

Category 3: Learner Self-Management Principles

Application of this principle: learner self-management principles consist of the actions that learners can take to self-implement CLT effects or strategies (Mirza et al., 2020, p. 157. This capability may be underpinned by affective factors including: approach vs. avoidance attitude, open vs. fixed mindset, self-explanation effect, or peer collaboration. At a more advanced level, learners can use the tools in Appendix F to self-diagnose their own knowledge and heutagogical barriers to learning, also called troublesome knowledge (Perkins, 1999) or bottlenecks (Middendorf & Pace, 2004). Further research is required to clarify the relationships between specific heutagogical factors and CLT effects and strategies and their most appropriate application.

Category 4: Curriculum Design Principles

Application of this principle: this refers to the modifications required to align the curriculum with the structure and functions of human cognitive architecture, therefore operating at governing level, or a top-down principle (see Appendix S) within the organisation. This principle may include: learning delivery policies e.g. the mastery learning model (see Appendix B); technological systems development and implementation; curriculum structure within knowledge domains to align with cognitive architecture e.g. use of the modality effect and other effects; factor analysis of curriculum concepts as a tool for eliminating redundant materials that don't contribute to schema automation; delivery schedules to include sprints and jogs and other factors related to the varying time and intensity of learning delivery.

The above four categories of effects and strategies have been synthesised into evaluation statements for inclusion within the instrument i.e. these are the evaluation questions or statements teachers will respond to in order to determine the extent to which the effects or strategies have been incorporated into the learning delivery. The wording of the statements may vary, but each one should relate to a specific effect or strategy. The following statements represent a possible format of these evaluation statements, with the relationship to an effect or strategy indicated in brackets:

Q1 The teacher holds Diagnostic Conversations with learners to (1) determine the status and quality of schema development (2) identify barriers to learning in both domain knowledge and heutagogical factors, for example approach vs. avoidance attitude, open vs. fixed mindset and (3) to identify the current learning and future work aspirations of learners.
<u>Effect/Strategy</u>: Prior Knowledge, Expertise Reversal Effect.

Q2 Redundant materials that do not contribute directly to schema automation have been removed from the course.

Effect/Strategy: Redundancy Principle, Removal of Extraneous Cognitive Load.

Q3 Materials that cause cognitive overload through splitting the learner's spatial or temporal attention have been removed from the course.

Effect/Strategy: Split-Attention, Redundancy

Q4 Curriculum delivery provides flexible time frames for learning e.g. sufficient time and delivery events [see Sprints and Jogs] for learners to master nodes of expertise to the point of automation.

Effect/Strategy: Time–to–Mastery, Worked Examples, Goal-Free Problems.

Q5 The course includes worked, faded and and full problem solvng tasks (see Full Examples) for novices until schemas are automated.

Effect/Strategy: Worked Examples; Avoidance of Means–ends Analysis as a learning strategy.

Q6 The course uses goal-free practice problems [where appropriate] for novices until schemas are automated.

Effect/Strategy: Worked Examples; Avoidance of Means–ends Analysis as a learning strategy.

Q7 Learners are trained to use worked, faded and full [complete, unscaffolded] problem tasks or examples (see Full Examples) to automate nodes of expertise. The term *full examples* is used for traditional tasks where learners are required to complete every step of the problem (see Full Examples) i.e. complete, unscaffolded problems

Effect/Strategy: Worked Example Effect, Completion Effect, Guidance Fading Effect.

Q8 In this course, self-explanation is taught as a skill and learners are taught to differentiate between high-quality and low-quality self-explanations.

Effect/Strategy: Self Explanation Effect; Schema formation and automation.

Q9 Learners are trained to use schema-validation skills, including: concept-mapping; relational diagrams; explaining concepts and processes to others; high-quality self-explanations; and visual and semiotic representations of concepts.

Effect/Strategy: Schema Automation

Q10 In this course, the learner's imagination is activated through visualisation to rehearse and review processes and related concepts.

Effect/Strategy: Imagination Effect.

Q11 This course uses affective/emotional means (stories, humour, interaction) to the extent that they support the formation and automation of schemas.

Effect/Strategy: Personalisation, Motivation.

Q12 During this course, expert guidance is available to learners when needed in order to model expert thinking and to automate schemas.

Effect/Strategy: Schema Formation and Automation.

Q13 The course engages both auditory and visual information channels to present non-redundant materieal i.e. where information is not duplicated in either channel.

Effect/Strategy: Modality Effect

Appendix Q: Reference Guide for Interfaces and Features of CLEMS

Table Q.1 CLEMS user interfaces with descriptions

Interface	Description of Interface
Administrative functions	This interface shows the administrative functions for assigning courses to teachers, including: 1. Navigation menu functions: Add courses to the system; Add teachers to the system; Assign courses to teachers; Log into teacher dashboard; 2. Function: General Evaluation and create NOEs; 3. Enter teacher ID; 6. Select course from drop-down menu; 4. Click submit; 5. View of course/s assigned to teacher in CLEMS. This figure shows that Algebra has been assigned to the teacher E Jones.
Teacher dashboard	This interface provided informations and functionalities for teachers e.g. the teacher login details. On this page teachers can select the option to: a. evaluate and increase the use of CLT strategies in a course, OR b. to evaluate the suitability of a course for individual learners in terms of its inclusion of CLT strategies.
Creating evaluations	On this interface, the teacher has the option of creating course evaluations.. The following functions are provided: 1**.** Teacher dashboard; 2. Log out link; 3. Name of course being evaluated (Algebra); 4. Active link shown for creating first of three course evaluations. Links to second and third iterative evaluation are not accessible until the first evaluation has been completed.
Evaluation statements	This interface contains the course evaluation statements, instructions and a evaluation rating key. The statements are designed to enable the teacher to identify the extent to which specific CLT strategies are used in the course, with blank spaces for teachers to enter rating scores.

Visualised reports/analytics	Visualised report interface (1) the teacher and course name are identified (2) a bar graph is shown with the teacher's rating levels for each evaluation parameter as completed on a scale of 1–10 (3) The risk level associated with each parameter is shown beneath the bar graph e.g. a rating may show a high risk to learners due to low level of inclusion of this evidence-based parameter in the course; risk also implies that learners may learn by rote and not understand the governing rule or principle of a problem-solving step i.e. at risk of not understanding why they are doing a particular action or step of a task. Teachers can control the number of parameters viewed by toggling different parameters on or off.
Access to Dynamic Knowledge Database (DKD) and Rcommender System	Visualised report interface (1) with teacher able to access Dynamic Knowledge Database (DKD) by rolling mouse over bar graph or list of statements. An example of an entry in the DKD for this statement is provided in Figure 10.3.8 (next page). This information supports the teacher in designing NOE interventions for modifying the course through the NOE form (7).
Node of Expertise Planner	A simple example of a NOE intervention plan for a course with fields for filling in learning design information (1). This form is activated in CLEMS by clicking the Create NOE button (see Figure 10.8, Point 7). This opens the form for the teacher to design the course modification NOEs. Links to resources may be added to this page or to externally hosted examples. The 4 examples contain additional explicit explanations (3) and (4) on the governing principle of the problem in order to foster the learner's transfer of the principles to other similar problems.
Course Re-Evaluation	A re-evaluation of the course (see 10.6) by the teacher may now show the above graphical report, where worked examples have been included in the course. Depending on the performance of learners from the intervention, further interventions can be created using the same parameter or a different parameter e.g. goal-free practice problems (parameter 3) can be developed for the course.

	After the first evaluation has been designed and implemented, teachers may return to the Teacher's Dashboard and conduct additional evaluations. This interface (4) shows the currently active 2nd evaluation option, with 1st and 3rd evaluations being inactive and greyed out. As noted in Figure 10.4, further evaluations may include the same or different parameters. This interface shows the page where teachers can select the option to evaluate and increase the use of CLT strategies in a course OR to evaluate the suitability of a course for individual learners. In this example, the options related to evaluating an individual learner are shown (3), (4), (5) and (6).
Learner Self-Evalaution Form	This interface shows a sample Evaluation 1 questionnaire sent to learners via email (1), which asks the learner to respond to self-reflective questions about their domain knowledge (statements 1–5) and heutagogical capability (statements 5-8). Responses to this questionnaire provide information to the teacher to inform a Diagnostic Conversation (DC) in order to develop a NOE for the learner. A limited selection of questions is shown in the questionnaire (2), with each question relating to a specific CLT strategy or heutagogical capability. In this figure, the sample questions 1–5 in the questionnaire relate to specific CLT strategies and questions 6-8 relate to aspects of heutagogical capability of the learner.
Combined Views	This interface shows the combined reports by the teacher and the learner. Notes: The teacher's course evaluation (1–5, patterned bars) is alongside the learner's response in the email questionnaire (10.4.2). In questions 1–5 the teacher and the learner are responding to the same parameters of the course. Questions 6-8 reflect the learner's response to heutagogical questions about self-determined learning capability.

Appendix R: Three scenarios for the application of CLEMS

This appendix provides supplementary information about the scenarios outlined in Chapter 10, Section 10.5.

Scenario One – Course level evaluation

In this scenario, an undergraduate Physics teacher uses CLEMS to evaluate and improve the extent to which CLT effects have been incorporated into a course (CLEMS can be used in any subject domain). Using the instrument, the teacher logs in to CLEMS and completes the standard questionnaire to verify the extent to which a course has been designed to include CLT effects. The questionnaire has hyperlinks to the Dynamic Knowledge Database (DKD) which has explanations and applications of each CLT effect which the teacher can refer to for clarification of terminology while completing the questionnaire. For example, a question could relate to the use of goal-free problems within varied contexts to support novice learners.

After completing and submitting the course evaluation questionnaire, the teacher will then view graphic feedback from the questionnaire on a dashboard that reflects the level of CLT effects used in the course as per the teacher's responses. Based on this feedback, the teacher selects one CLT effect to increase in the course. It is a principle of using CLEMS to identify one key strategy to improve at a time, as changes to a single variable will facilitate greater accuracy of interpretation of resulting outcomes. In addition, changing a single parameter requires less time from a time-stressed teacher's schedule. For example, the course may have a low level of inclusion of goal-free problems or worked examples; the teacher will select one of these effects to improve in the course.

Based on this feedback, the teacher then creates a course improvement plan, supported by the comprehensive reference library of collated CLT effects and examples of application in the DKD. The DKD also contains guidelines for the correct formatting of specific effects for teachers who may be unfamiliar with the process. Thus, CLEMS also has an educative function to support teachers in acquiring expertise in the application of CLT effects and strategies in practice (Niess & Gillow-Wiles, 2017). Teachers will refer to instructions for how to include not only problem solving steps, but the thinking behind each step in order to foster deep, inferential learning that supports the far transfer of knowledge. Through this modelling approach, learners will have the opportunity to practice problem-solving steps while being prompted, cued and directed to review and internalise the mental processes that support them.

In creating the improvement plan, teachers will be provided guidance on how to eliminate redundant information and extraneous cognitive load, referred to as one of the wastes in higher education (Balzer, Francis, Krehbiel & Shea, 2016; Mayer & Moreno, 2010) and use spatially and temporally contiguous formatting to manage cognitive loads by addressing the split-attention effect for novice learners engaged in high element interactivity learning tasks (Mayer, 2005; Sweller, Ayres & Kalyuga, 2011).

Learning tasks will be expressed as NOEs, where the goal of teaching within a CLT pedagogy focuses on the accurate formation, validation and automation of schemas. For clarification, a NOE differs from a learning outcome, as it represents an integrated series of executed processes that may draw functions from different levels of applied expertise. For example, a NOE, such as solving a contextualised vector problem in Physics, may include arithmetical and trigonometric functions, knowledge representation skills and application of previously learned rules or formulae. The idea of a NOE is to model functional processes as well as expert thinking processes to the learner within a knowledge domain i.e. how a physicist would think about the problem. Moreover, a NOE shifts the process from shallow or non-inferential learning i.e. just knowing about a subject, to a deeply-embedded, inferentially-linked and demonstrable mental model that represents a new level of expertise (Kieras, 1998; Page, 2016). The intention is for every learner to master the NOE within a flexible time framework, implying that a priority is placed on expert functioning at the current level of the expertise continuum (Dreyfus & Dreyfus, 1980) or the level of the learning spiral (Bruner, 1960).

When the NOE has been created, the teacher sets start and finish dates to run an implementation cycle e.g. over one day, a week or one term. At the end of the implementation cycle, the questionnaire will be completed again by the teacher and the post-intervention feedback provided by learners will be viewed by the teacher on the CLEMS dashboard. For example, goal-free problems may now be reflected as a standard pedagogical feature of the course; additionally, various contexts where the NOE may be applied have also been included in the course. The progress of learners will also be monitored to ascertain the impact of the intervention, reflecting a dual evaluation process. This represents the double-loop evaluation model posited by Argyris and Schon (1974): the course is evaluated for content of evidence-based CLT effects as well as learning outcomes in terms of the learner's attainment of prescribed NOEs. The NOE may be stored and accessed for future use or for sharing within the community of practice.

This process may be repeated at the discretion of the teacher as part of an overarching CI policy and the graphical output of each intervention will tracked and monitored over successive improvement iterations. In this way, CI of learning design is facilitated through the gradual increase of selected effects e.g. a series of course improvement cycles may occur to embed worked examples, goal-free problems and the removal of redundancy from courses over a set time period. This process aligns with a key purpose of CLT, which is to increase the learner's level of expertise through the formation and automation of schemas in long-term memory, evidenced by the attainment and demonstration of increasingly sophisticated levels of domain-specific expertise (de Groot, 1965). The increase of CLT effects in a course therefore constitutes a strategy for ensuring that every learner advances towards expertise satisfactorily and learners are not left to flounder in their progression towards expertise without guidance (Clark, 2013) at any point (Kirschner, Sweller & Clark, 2006). The implication for curriculum design is that at no point should learners be left to make sense of the "entangled web of information they are navigating – each imposing a heavy load on STM and attention" (Gobet, 2005, p. 198). Using this process, courses become embedded with an increasing proportion of CLT effects over iterative improvement cycles. By applying this process, teachers also gain increasing understanding of how apply CLT effects as a standard format of instruction for the future development of course content. Moreover, explanations may be embedded within courses to inform learners of what CLT effect are and how they are used, thus equipping learners with self-management skills to format content for their own studies e.g. how to use the goal-free effect to reformat a traditional problem or how to use the imagination effect for revision during studies,

Scenario Two – Individual learner evaluation

In this scenario, CLEMS is used by the same Physics teacher to evaluate and align learning interventions with the needs of individual students. First, students complete a self-evaluation questionnaire that provides a profile of both their current subject domain knowledge (prior knowledge) and their heutagogical capability, which includes their current experience of barriers to learning. This process may be likened to a medical practitioner taking a patient's history prior to diagnosing issues, or a patient undergoing a triage process before being admitted for hospital treatment. When the teacher has viewed the learner's questionnaire responses, the teacher engages the student in a Diagnostic Conversation (DC) using the tools provided such as the Knowledge/Heutagogy Quadrant (see Figure 10.16) and the Novice-to-Expert Learning Pathway (see Figure 10.17) to identify the barriers being encountered by the learner at a granular level. For example, the teacher may identify that the learner doesn't understand the difference between concepts of mass and weight and is therefore unsuccessful in solving problems that use these concepts. Alternatively, the teacher may identify that a learner has a poorly formed concept of kinematics formulae and is not able to apply them correctly to problems.

The teacher's task is then to rebuild the cognitive model of the concepts used by the learner, through concrete examples (if applicable), useful analogies and metaphors. The operation of a corrected or repaired thinking model (Chi, 2000) is predicated to result in greater fluency of execution of problem solving, as well as the learner experiencing lower cognitive load through the change from laborious, step-by-step execution requiring intense concentration ('working out' problems based on means–ends analysis), to the fluent execution of problem solving tasks based on the activation of prior knowledge schemas. Teachers may use additional tools during the DC e.g. the seven levels of schema quality, the seven levels of expertise (see Section 10.5) or the Fluency Plus/Minus One Model of Schema Automation (see Appendix F). Through the process of comparison with an external evaluation of their performance levels in the specific knowledge domain, the learner gains an accurate understanding of their level of expertise and may be better equipped to self-manage and self-regulate their own learning. The teacher can inform and encourage the learner to use these tools to facilitate reflection, self-management and self-regulation within any learning experiences.

When learning barriers have been identified, the teacher progresses to the next step of creating a NOE to address the specific barrier being encountered by the learner. The DKD will be accessible to provide clarification of effects and examples of strategies for the teacher to formulate an appropriate NOE. For example, the teacher might discover that the learner has a low level of self-explanation capability or the learner is able to self-explain, but only at a surface level without evoking deep connections and inferences during the self-explanation process. Alternatively, a learner may have an erroneous understanding of a concept or an that requires a repair intervention to support the learner in acquiring a more accurate and efficient mental model. In these cases, CLT strategies are then used to design NOE learning experiences that advance the learner towards a deep, automated understanding of the interconnected components of the concepts. The teacher also sets a realistic time–to–mastery goal in collaboration with the learner, based on an appraisal of the time needed by the learner to master the NOE. Learning time may be expanded or contracted through the use of sprints (intensive learning environments with high levels of expert support) and jogs (less intensive, self-managed learning environments). For example, a teacher may negotiate with the head of department for a full-day intensive training workshop that will include group and individual work as well as lectures from visiting physicists to explain how they think about and solve problems. Intensive workshops may vary in length depending on the prior knowledge of learners and the level of expertise which learners need to acquire. The assumption underpinning this process is that the learning environment will be structured to support learners at their individual level of needs until schema formation and automation is achieved through deliberate, extended practice, i.e. mastery of the core concepts and knowledge base of the discipline. A flexible approach to the time assigned to learning is one of the characteristics of the personalised learning framework implied by CLT, where learners are provided with a mass of prior knowledge through deliberately selected strategies and where the narrow limits of change principle is factored into the design of learning environments.

Should a teacher only make adjustments to entire course content, or to both courses and individual learning plans of learners? It is suggested that Scenario One may be sufficient to adjust the course design to the needs of the students where a learner cohort has a high level of homogenous capabilities. However, where cohorts have students with wide-ranging prior knowledge and learning capabilities, the individualised functions described in Scenario Two may be used for all students, or only for specific students. As per Scenario One, the same functionalities for CI may be applied to NOEs for individual students as for courses.

CLEMS may be useful where incremental, evidence-based improvements to learning delivery to both courses and individual students are needed, thus introducing incremental transformation to institutions in terms of evidence-based practices.

Discussion of Scenarios One and Two

The above two scenarios describe how the IA construct serves as a model for developing a technological framework to aggregate the effects arising from CLT into an evidence-based standard within a tangible and useable software instrument. The intention is for CLEMS to be used to facilitate the implementation of CLT effects into courses and individual learning experiences through targeted NOEs. CLEMS has the functionality to monitor the impact of the interventions on learning outcomes over time. The monitoring and measuring functions are a critical function of CLEMS, since the learner's growth in expertise within a knowledge domain as well as learning capability can be monitored and adjusted, or courses can be transformed through embedding increasing the use of CLT effects and strategies.

The double-loop function of CLEMS is a theoretical construct that is realised through technological functions that record and monitor two parallele processes in order to evaluate the impact of each process on the other. A learner engaging in solving a problem using a traditional approach e.g. a memorised algorithm for solving a calculation problem, represents single-loop learning. When the teacher deliberately modifies strategic pedagogical interventions to align more specifically to the needs of learners e.g. to introduce worked examples or goal-free problem formats, double-loop learning is facilitated; not only has the procedure of problem-solving changed for the learner, but the way of approaching the problem from a learning design perspective has been modified.

Argyris and Schon (1974) observe that double-loop learning does not replace single-loop learning. Single-loop learning reflects the status quo or traditional approach to performing a function, also called a theory in use. Moreover, single-loop learning is essential since it makes up the bulk of predictable learning activities. However, single-loop learning activities may exert a tyrannical effect if they are never challenged. Double-loop learning, however, modifies the overarching or governing variables (e.g. the settings) of one's programs or systems and causes incremental ripples of change to splay out over the entire system of theories-in-use, or actual practice (Argyris & Schon, 1974; Argyris, 2002, 2005). This represents the bottom-up transformation process advocated by the LASO model, which may be applied to facilitate transformed learning design processes through the incremental increase and monitoring of the impact of CLT effects and strategies in courses.

The way that double-loop evaluation is implemented is through the capability of CLEMS to monitor the increased use of CLT effects in learning environments as well as evaluating the learner's advancement in domain knowledge and heutagogical skills. Each level of evaluation is implemented, stored in the instrument's database and then monitored through ongoing cycles of implementation. CLEMS is able to track, over extended time periods, the individual learner's mastery of NOEs as well as their heutagogical capability. A teacher can search the database for the learner's profile in advancing towards expertise and immediately view comparative analysis charts to understand where a learner might be experiencing difficulty. At a higher level, administrators can observe the trend towards changes in evidence-based practice over short, medium and long-term time frames. Through the use of this process, an educational institution can manage a transformation of learning design to be fully based on CLT effects and strategies.

The inclusion of the double-loop functionality of CLEMS developed in this study implies that every learning intervention needs to be cyclically and continuously monitored and improved. This function of CLEMS counters the assumption that the application of CLT effects may be reduced to a simplistic cause-and-effect process. In other words, it is not taken for granted that simply introducing a CLT effect into a learning program will guarantee improved learning outcomes. This is due to the fact that while CLT effects were originally validated under controlled, laboratory conditions in order to establish evidence-based effects, every learning environment consists of a unique range of variables that makes it fundamentally different from a controlled, experimental environment, therefore requiring validation within each unique educational environment. This approach is also validated from CLT research, in which the expertise reversal effect (Kalyuga, 2007; Kalyuga, Ayres, Chandler & Sweller, 2003) forms an overarching or governing principle in all learning environments. The adaptive requirements of learning design under the expertise reversal effect principle therefore implies the necessity of dynamically modified learning interventions as the base standard (Kalyuga, 2009a, 2009b). This in turn implies the necessity of a systems approach to supporting the adaptation of learning materials to adjust to increasing levels of expertise gained by learners.

CLEMS has therefore been designed using a systems approach in order to support the increase of CLT effects and strategies, but also to evaluate their efficacy in varied learning environments. CLEMS therefore facilitates a CI cycle through a process designed to narrow the gap between current practices and evidence-based practices by use of a double-evaluation process: first, by aligning learning with experimentally-validated effects; secondly, by testing these effects during in situ learning environments.

In summary, the development of CLEMS as a software application emerged from a theoretical model derived from the literature review which forms the basis of the conceptual framework of the current study. The inherent complexity of learning environments (Brown, 1992), which include learners with differing levels of learner prior knowledge (Sweller, 1988), as well as the influence of the expertise reversal effect (Sweller, Ayres, Kalyuga & Chandler, 2003), combine to form learning environments with unpredictable features. It is due to the unpredictable nature of learning environments that interventions need to be implemented systematically so that greater points of stability may be developed in terms of understanding the prior knowledge of learners and the extent to which learning design is evidence based. CLEMS facilitates the process of introducing CLT interventions with predictable effects. It also has the capability of conducting ongoing evaluation of the impact of the implemented effects within in situ learning environments over iterative improvement cycles.

Scenario 3 – Using CLEMS to conduct in situ experimental testing of learning effects and strategies

Scenario 1 described a method of using CLEMS to increase the use of CLT effects in courses. Scenario 2 described how CLEMS could be used to design interventions for individual learners, as well as monitor and track the impact of these interventions over time.

Scenario 3 suggests a method for using CLEMS to implement in situ experiments for validating the effectiveness of specific strategies. Many variations in experimental design may be facilitated to evaluate the impact of different CLT effects and strategies, but the following examples are suggested for accomplishing this goal:

1. A class can be divided into two halves, with learners randomly assigned to each half. Alternatively, two different classes may be selected to conduct the experiment. Lessons can be then be designed with and without the inclusion of specific variables in the form of CLT effects e.g. goal-free problems or self-explanation prompts as a method of improving learners' domain knowledge and heutagogical capability. As part of the experiment, learners in the group with the strategy as a variable can be instructed in the processes and expected outcomes of the interventions. The lessons can then be run for a specific time period e.g. a term, or a semester and the learning outcomes between groups compared. To strengthen the experiment, a number of classes can be run in parallel. The results, which will be permanently stored in CLEM's database (subject to privacy protocols), can then inform the design of learning in the particular knowledge domain.

Principles of Applying CLEMS in Practice

CLT has much to offer in the advancement of evidence-based teaching practice and CLEMS provides an architectural framework for its implementations and monitoring.

The above scenarios included the following key steps of analysis of the quality of learning in terms of CLT effects:

1. analysing the extent to which learning courses include CLT effects, with resources for increasing them.
2. administering diagnostic tests to learners to determine prior domain knowledge levels and heutagogical capability.
3. conducting DCs to determine the prior domain knowledge levels and heutagogical capability of learners using additional resources such as the Knowledge/Heutagogy Quadrant and Expertise Pathway model (see Chapter 10).
2. creating NOEs by accessing the dynamic knowledge database (DKD) of CLT effects that is built into CLEMS as well as using additional supporting resources.
3. implementing the NOE within a defined time framework.
4. conducting VCs to determine the impact of the intervention.
5. repeating these steps as part of a continuous improvement (CI) process.

An implication arising from CLEMS is therefore its role in establishing principles of evidence-based practice, contributing towards a common language of evidence-based practice and serving as a catalyst to communities of practice to form around CLT as a standard part of learning delivery in higher education environments.

This study therefore represents a contribution to advancing the pedagogical practice of CLT. The most recent scholarly publication on advances in CLT (Tindall-Ford, Agostinho & Sweller, 2020) does not include technological advances in implementing CLT as a research direction. It is hoped that this study will support the establishment of this research direction and give rise to the development of further technological architectures for implementing and managing CLT strategies with increasingly sophisticated digital capabilities and tools.

Moreover, it is envisaged that CLEMS may support scholarly teaching by making evidence-based teaching strategies arising from CLT more accessible to educational practitioners and it may contribute to the scholarship of teaching by providing a technological tool for facilitating experimental practice that can be documented and published in peer-reviewed journals (for example the Journal of the Scholarship of Teaching and Learning, 2017), thus providing a mechanism for bringing educational practitioners a step closer to publishing their research findings (Richlin, 2001; Richlin & Cox, 2004).

Appendix S: The LASO Model of Organisational Transformation through Technology

The LASO (Leadership, Academic and Student Ownership) Readiness model by Uys (2000, 2007, 2015) provides a feasible strategy for implementing evidence-based practice in education using the instrument developed in the current study, since: "The LASO Model is an approach to ensure enterprise-wide technological transformation in higher education through a strategically developed framework based on a clear and unified vision and a central educational rationale" (Uys, 2007, p. 1).

It is suggested that the pairing of CLEMS with an implementation strategy such as LASO will provide a framework for addressing issues of institutional readiness required at multiple levels: organisational senior leadership and policy; technological implementation; teaching practice and student engagement. As a multilayered model, LASO aligns with the ontological perspective of Critical Realism (see Chapter 6) on which the study is based; with CR, multiple layers of realities within organisations will be taken into consideration, as well as their underpinning governing mechanisms. Moreover, CR examines the conditions under which social phenomena can or may exist, thereby providing an implementation framework with built-in validation structures at a foundational level. For example, CR seeks to account for layers of reality comprising the *real* (the realisable potential of the system), the actual (the extent to which the system has reached its potential) and the empirical (the experiential aspects of the implementation by stakeholders).

LASO posits a three-tier organisational transformation with the following characteristics:

a. top–down, consisting of leadership strategies and organisational policy;

b. bottom–up, consisting of academic and student ownership of systems and technology, and

c. inside–out, consisting of technological transformation implementation strategies, as well as connections between the organisation and the outside world and between the organisation and other organisations. LASO therefore provides an implementation model for technologically enabled learning environments without compromising on the roles and needs of people within the organisation.

LASO has been tested in in situ environments and provides the advantages of having been refined through practical experience in large scale higher education technological transformation projects, with its key focus defined in the following terms:

> The pervasive use of eLearning in higher education has made it imperative to understand what the critical issues are when implementing enterprise wide learning strategies to support a digitally enhanced learning environment. The LASO model attempts to address the wider context in which the infusion of eLearning takes place in higher education and acknowledges that the process of enterprise-wide technological transformation is complex with many dislocations, dilemmas and uncertainties, given that people are central to this transformation process (Uys, 2007, p. 1).

Suggested guidelines for using the LASO model to implement CLEMS in a large institutional context may be as follows:

First, the implementation of CLEMS needs to be policy driven with the end goal of the implementation clearly defined within the project plan. This represents the top–down aspect of the LASO model. Next, the implementation will need to be managed by a steering committee with competencies in project implementation and a knowledge of information systems as well as learning management systems. The steering committee will need to define and appoint stakeholder groups, including: early adopters (staff) who might be identified to participate in a pilot study; management groups who will use the data from the pilot study to inform policy and executive decisions; student groups who will be included in the pilot study; technology systems team members; institutional project managers; and financial resource officers to report on financial aspects of the implementation. Early adopter staff will require training in the use of the instrument and its underpinning processes, as well as in the use of diagnostic tools for facilitating DCs, developing NOEs, facilitating VCs and managing this entire process within the unified architecture of the instrument, which will also require financial resourcing. Training of early adopters might occur through a blended learning model, including both face-to-face training and online course work. It is recommended that a small sample group of learners be nominated to participate in the pilot program; this group may be appointed through advertising for volunteers on campus and may include students with a range of knowledge and heutagogical capability. The selection of students will require awareness by selectors that the strategies arising from CLT are particularly suited to support the acquisition of complex knowledge by novice learners. This category of learners may include undergraduate students in specific knowledge domains e.g. first-year Physics or English students, or alternatively more experienced students who are new to a knowledge domain e.g. a third-year student starting a course in a subject where they have no or low prior knowledge such as a Science student starting a new course in Greek Theatre. Remote students may also participate subject to interest and availability of technology to support their participation. The initiation of the project as a pilot study with a small group of students represents the bottom–up aspect of the LASO model, with encouragement of the organic growth of the project to facilitate the instrument becoming part of the institution's DNA (Baskin, 1998).

After the first pilot implementation has been completed, the feedback from all stakeholders can be collated and reported to the steering committee. The report can include technical feedback on the use and integration of CLEMS (if applicable) into the current learning management system. If the results of the pilot study warrant continuation with the implementation on a broader scale, a small pilot group can expand into a larger group for subsequent implementations. A broader implementation strategy will require further planning in addition to the factors suggested to this point. For example, in the case of an implementation of CLEMS with a cohort of 500 students, groundwork will need to be conducted to clarify the purpose of the implementation and if it is suitable for e.g. all students, some students, all courses or some courses.

The scaling up of the implementation will also require the consideration of how the personal interviews with students in the form of DCs and VCs will occur, since it would not be possible for one teacher to conduct these single-handedly.

Additional focus groups would need to be conducted to determine how to manage the embedding of DCs and VCs into the DNA of the institution. Additional communities of learning within the institution may need to be fostered to use the system efficiently, with regular training provided in the use of the instrument and to ensure that users have an in-depth knowledge of tools and the range of cognitive load strategies e.g. rapid assessment, goal-free problem design and worked-example problem design, in order to determine which students need what level of support. The option may exist in some institutions to train high capability students as tutors as part of a ‘buddy’ system; webinars with large numbers of students may be conducted; large ‘conference style’ intensive training sessions may be held. In a longer-term plan (3–5 years) CLEMS may be introduced as part of teacher training programs at university so that student teachers arrive in their first teaching role with well developed levels of expertise in the use of CLEMS and its supporting processes. Ultimately, it is suggested that CLEMS should become community owned so that ongoing development can occur in a way that ensures all institutions have the benefit of using CLEMS if they determine it is suitable for their purposes.

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