WHAT FACTORS INFLUENCE LEARNING OF PSYCHOMOTOR SKILLS BY DENTAL STUDENTS?

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Abstract

Several key factors have been identified that relate to skill acquisition: a) ability, b) motivation, c) thinking processes and d) learning environments. Other health professions have used learning theories to inform study designs when investigating skill acquisition but this approach has not been adopted routinely in dentistry. Previous studies in dentistry have focused mainly on the predictive value of assessments used in dental admissions, eg ability tests, rather than trying to clarify how factors such as motivation and ability influence skill learning. This dissertation explores the influence of the above key factors on dental performance and outlines theoretical-based implications for practice in operative technical courses.

To clarify how motivation, ability, thinking processes and learning environments influence the acquisition of psychomotor skills in operative dentistry, two cohorts of dental students were studied from different years of the Bachelor of Dental Surgery program at The University of Adelaide. To determine the nature of the relationship between individual differences in ability, motivational determinants and performance on routine operative dentistry tasks, a cross-sectional study (Phase I) was conducted of third-year students. Phase I also investigated the use of motor learning parameters by students during completion of a routine operative task.

The second phase of the study investigated individual differences in ability of a different cohort of students and was carried out during the second year. This was achieved by exploring the contribution of ability and motivation determinants to changes in motor performance throughout the operative technique course. The study also explored external factors that were related to performance, ie learning experiences that students reported had influenced their skill learning, as well as motor learning parameters they used during the activities.

Both quantitative and qualitative approaches were used to explore the previously noted key factors using a range of instruments, eg psychometric tests, a motivation survey, a retrospective think-aloud technique and critical incident reports. Significant positive associations were found between cognitive, psychomotor and motivation scores and performance in operative dentistry. This relationship varied across different stages of learning in the dental program. Students tended to focus on evaluating their outcome rather than evaluating their processes to achieve a task. Three themes related to learning environments were derived from critical incident reports and follow-up interviews: roles of tutors in providing a positive learning environment; perceptions about the quality of cavity preparations, ie "learning from errors"; and roles of peers in self-assessment of outcomes.

This study has provided insights into individual differences in the learning of psychomotor skills by dental students as a result of inherited factors, eg ability, as well as the roles of the learning environment in enhancing learning. This dissertation presents the implications of these findings for the design of quality learning activities in operative technique courses.

Declaration

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Nattira Suksudaj

Dated this………………………………**day**……………………………...**2010**

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Summary

The acquisition of psychomotor skills is clearly a key competence in dentistry and also in other health profession areas, such as surgery. Several significant factors have been identified that can influence skill acquisition. Recently, skill acquisition and motor learning theories have been used to improve understanding of skill learning in surgical training. However, our knowledge of key factors associated with the development of psychomotor skills in dental education is inadequate. Specifically, research into psychomotor skills shows limited application of the theory of skill acquisition in study designs. As a result, our understanding of the roles of key factors in skill acquisition in dentistry is incomplete.

Key factors that have been reported to influence psychomotor skill acquisition include a) internal factors, eg level of motivation, ability and learning processes, and b) external factors, eg the learning environment or setting experienced by learners during practice which will also be referred to as 'the practice environment' in this dissertation. Therefore, the purpose of this study was to clarify differences in performance among dental students in relation to internal factors in skill learning. In addition, the study aims to clarify aspects of the practice environment that support students' learning of skills. Therefore, the two main research questions for the current study are; a) what is the relationship between performance on operative skills and internal factors, eg motivation, ability and learning processes, and b) what learning activities do students perceive to be effective or ineffective in supporting their learning. The first research question should provide insights into understanding how motivation is associated with different levels of performance and which key abilities

are required in learning dental skills. In addition, an understanding of students' learning processes should assist in clarifying differences in performance during completion of an operative task. Furthermore, this information should be useful for design of learning activities to optimise outcomes. The second research question should help us to identify aspects of the practice environment that enable positive learning experiences.

To explore these research questions, the current study was conducted in laboratory classes as part of an operative technique course (see Chapter 2: Methods). This involved a cross-sectional study with two cohorts of students, third-year (Phase I) and second-year (Phase II) students. Research techniques and materials were selected based on a range of sources of validity evidence (results presented in Chapter 3) to ensure valid interpretations of the data collected. Chapter 4 presents results on the relationship between dental performance and ability and motivation for both cohorts. Chapter 5 presents results on the use of motor learning parameters by students during completion of an operative dental task. Finally, Chapter 6 presents results on students' perceptions of effective and ineffective aspects of the practice environments in an operative technique course.

For the first research question, a relationship between dental performance and motivation, as well as ability, was noted. This relationship depended on the stage of learning, which was somewhat consistent with skill acquisition theory. Specifically, performance by students in second year was associated with broad-content cognitive ability while the performance of third-year students was influenced by psychomotor ability. Those aspects of this research question relating to motivation and ability were answered but the limitations of the study need to be acknowledged (Chapter 7, section

7.7). In summary, motivation and ability, including both cognitive and psychomotor ability, appear to be key factors that influence learning outcomes in operative dentistry. Furthermore, the current study explained the learning processes that students use during completion of an operative dental task. Similar patterns of learning processes were reported among students with variable levels of performance. These results highlighted key learning elements students used during the dental task. Future studies should focus on the design of activities that make use of students' motivation as well as identification of key learning processes used in operative dental tasks to improve performance.

For the second research question, the current study highlighted both effective and ineffective learning experiences from the students' perspective. Students acknowledged the role of tutors in supporting skill learning in the operative technique course. For example, effective learning experiences were noted when tutors arranged group discussions on 'how to do' the exercises. Ineffective learning experiences were noted when students were unsure and became stressed about their knowledge base. Future studies involving various interventions are needed to determine which learning experiences encourage better performance among students.

In summary, the current study provides new insights into factors that influence learning of psychomotor skills in operative dentistry and also suggests how dental educators could apply the findings when designing operative activities (Chapter 7, section 7.8).

Chapter 1 - Introduction and rationale for the study

The focus of this dissertation is on psychomotor skill development in dental students. Specifically, it will investigate the influence of key factors identified in the literature on skill development in dental students. As a result, this chapter describes issues related to the importance of psychomotor skills in dentistry, the context of learning and teaching these skills in dental education, and the theoretical background in relation to skill acquisition. Sections 1.1 and 1.2 outline the importance of psychomotor skills in dentistry and the definition of the term 'psychomotor skills' that is used in the current study. Section 1.3 describes current approaches in dental education in relation to the development of these skills and discusses relevant issues in research into the development of these skills in dentistry. Section 1.4 discusses key factors related to the acquisition of psychomotor skills that are drawn from related theories, ie motivation, ability, motor learning parameters and the practice environment. The practice environment refers to the learning environment or setting experienced by learners during practice and will be used in this dissertation. This section provides a discussion of the relationship between these key factors and the performance of psychomotor skills reported in previous studies in dentistry and in other related disciplines. Finally, sections 1.5 and 1.6 provide a summary of previous studies and a rationale for the current study including specific research questions.

1.1 Psychomotor skills in dentistry

The acquisition of psychomotor skills is a key competence in dentistry (Tedesco, 1995). As dental procedures need high precision and involve irreversible surgical work, dental students are required to develop these skills before providing patient care.

Indeed, a wide range of tasks of variable complexity, requiring different levels of psychomotor skills, are used daily in dental practice. For example, routine restorative work of general practitioners needs precise eye-hand coordination and the application of three-dimensional forms. Furthermore, the increasing number of dental innovations, for example, high technology devices and new materials, means that dentists need to be continually developing and extending their psychomotor skills. For all these reasons, dental schools need to develop and provide up to date dental curricula, including evidence-based education for students in psychomotor skills (Iacopino, 2007).

1.2 Definitions of psychomotor skills

Various terms have been used to refer to psychomotor skills, eg motor skills, technical skills and manual skills. Psychomotor skills can be defined as 'those that require the subject to have the capacity to co-ordinate sensorial information and muscular response in order to perform a determined task' (de Andres et al., 2004). These skills are involved in controlling muscles signaled by the brain and motor neural pathways resulting in purposeful movement (Rose and Christina, 2006). The term 'psychomotor skills' has sometimes been confused with the term 'ability'. In fact, skills in any task are acquired through practice while ability is an inherited attribute underlying certain skills that is not modified by practice or experience (Schmidt and Lee, 2005). For instance, with the same amount of practice, two individuals could reach the same level of skill but the one with greater ability would have the potential to achieve a higher level of skill in a shorter time period. According to the above definitions, psychomotor skills in dentistry are involved in activities that need the coordination of finger and hand movement as a result of cognitive planning. The activities might include several tasks, eg control of an ultrasonic scaler, control of bur movement in a cavity preparation for restorative work, or crown preparation for prosthodontic work.

1.3 Current approaches in dental education related to skill development

1.3.1 Types of learning methods

In most curricula, the opportunity for dental students to develop the required psychomotor skills is provided via preclinical laboratory courses. Due to the complexity of skills needed, students spend a significant amount of time developing and practising these skills either through preclinical activities or when providing care for patients in the clinic (Tedesco, 1995). Activities range from the use of traditional benchtop exercises including manikins to high technology devices such as virtual reality simulators (Wierinck et al., 2005). In preclinical laboratory sessions, students are provided with a range of exercises that require the integration of theoretical knowledge. These exercises allow them to encounter simulated scenarios that they might confront in clinical situations.

In the benchtop model, students are often required to prepare their work in a laboratory setting, eg in operative dentistry, where they may cut a cavity in a typodont plastic tooth using a rotary instrument but without the use of a mouth mirror. Innovations such as lifelike manikins and simulators have been introduced to provide a more realistic simulation of the clinic environment, eg synthetic teeth are mounted in dental arches, eg Frasaco™ with rubber cheeks and lips to simulate soft tissues. These lifelike manikins allow students to reproduce their work in a physical environment that is similar to the real-life situation in the clinic, eg when working on maxillary teeth, students are required to position the mouth mirror to provide indirect vision of the handpiece and teeth. Students are usually observed in groups by a tutor who provides feedback. With advances in computer technology, students' performance during completion of a task can be monitored by simulators, eg DentSim™ (Wierinck et al., 2005). For example, with this computer-based technology, educators are able to indicate which types of operative tasks are required and then set the device to provide feedback about students' outcomes in relation to the form and dimensions of their cavity preparations.

The introduction of computer-based simulation approaches has resulted in questions being raised about the effectiveness of these advanced facilities compared with conventional approaches. It has been questioned whether these simulators can improve skill learning in preclinical contexts and enable students to transfer these skills to direct patient care (Bradley and Bligh, 2005; Okuda et al., 2009). Although it is generally agreed that these innovations show great promise in surgical skills training (Wong and Matsumoto, 2008) and in dentistry (Wierinck et al., 2006), the conventional laboratory environment is still considered to have a place in facilitating interactions with tutors and in the provision of critical feedback (Quinn et al., 2003). Generally, with computer-based simulation approaches, tutors still play an important role in helping students to gain experience, to provide feedback and to act as role models (Quinn et al., 2003).

One of the key issues with the use of simulators is the apparently limited integration of theories of skill development in the design of learning activities. This is critical to ensure optimal learning experiences are constructed, especially for novice students (see section 1.4), eg the use of skill acquisition and motor learning theories are needed to inform the design of learning activities (Brydges et al., 2007). However, at present there is little evidence of integration of current theories of psychomotor skills learning into the design of learning activities that are critical in dentistry (Tedesco, 1995; Wierinck et al., 2005; Wierinck et al., 2006).

1.3.2 Research into psychomotor skills development in dentistry

Psychomotor skills can be studied from two main perspectives: motor performance and motor learning (Rose and Christina, 2006). Motor performance refers to the explicit physical actions or the outcomes of a task (Schmidt and Lee, 2005). For example, in the task of cutting a cavity preparation in a tooth, motor performance usually focuses on an assessment of the quality of the final prepared cavity in the tooth. As a result, there is no information about students' skills used during the preparation which in turn limits the type of feedback that can be provided. In contrast, motor learning refers to the capability of individuals to understand the processes and outcomes required, leading to permanent changes in their performance (Schmidt and Lee, 2005). It has been suggested that studies of skill acquisition should assess both of these aspects in order to obtain data that can be used to support skill learning (Schmidt and Lee, 2005). Most studies in surgery, as a comparable profession, have generally investigated both perspectives in understanding how well participants are able to learn a task, eg Dubrowski et al (2005) and Brydges et al (2007). However, dental education research mainly tend to investigate psychomotor skills in terms of motor performance outcomes (Tedesco, 1995), with limited assessment of the learning processes for psychomotor skills development.

1.3.3 Assessment of performance in dentistry

Motor performance in different professions has been a major focus of investigation recently. A range of instruments has been used to assess technical performance in surgery (Hamstra, 2006), eg time, hand motion, final product rating, checklists and expert global ratings. Some of these instruments have been investigated for their validity and reliability in measuring the competency of surgical skills (Saleh et al., 2006). In studying skill acquisition in dentistry, motor performance generally has been assessed using final product ratings, eg grades for cavity preparation and average grades for clinical and/or practical performance (de Andres et al., 2004; Heintze et al., 2004). These grades generally have been provided through tutor assessment processes. A key issue in such studies is to ensure the validity and reliability of instruments used for assessment of technical performance as these influence the interpretation of results (Cook and Beckman, 2006). However, validity and reliability testing of instruments used in studies in dentistry are generally limited (Gillet et al., 2002; de Andres et al., 2004).

One of the key principles of validity is the identification of the specific construct being measured. Beckman et al (2005) suggested that validity is focused more on providing evidence to support meaningful interpretation rather than focusing on the property of the assessment tool itself. They described five sources of validity evidence in the context of medical education. These sources included content, response process, internal structure, relationship to other variables, and consequences. The definitions of these sources (Beckman and Cook, 2007) are given as shown in Table 1.1. However, previous studies have not explicitly addressed these aspects and this tends to limit the usefulness of the results reported. For example, in the study of Gillet et al

(2002) involving cutting a cavity in a resin tooth, as a measure of manual skills, the internal structure of the instrument was not explicitly addressed. Specifically, there were no other sources of evidence to ensure that the students in their study understood the test as designed. This may result in over or underrepresentation of some facets of the construct of interest (Haynes et al., 1995), ie manual skills of the students. Furthermore, the performance in manual skills was assessed by four examiners, but no explicit information about the agreement of grades assigned for the performance was provided. As a result, grades assigned for the level of manual skills might not be reliable, and therefore, could lead to misinterpretation of the findings.

Table 1.1 Validity: sources of evidence, definitions and examples (Beckman and Cook, 2007)

In summary, limitations of previous research into psychomotor skill development in dentistry have been identified, namely limited use of theories of skill learning, focus on only one of the perspectives for the study of psychomotor skills, ie motor performance, and limited analysis of the validity of instruments used. The following sections will review key aspects in skill acquisition that have been discussed in the literature. These key aspects have been shown to influence student learning of psychomotor skills in various professions, eg sport sciences, physiotherapy, surgery and also dentistry.

1.4 Skill acquisition theory: factors related to skill acquisition

The fundamental concept of skill acquisition has been established over the last few decades. Several models have been proposed to describe how skilled performance is acquired during practice. For example, Fitts and Posner (1967) proposed three phases of skill acquisition based on information-processing perspectives, ie a) an early or cognitive phase, b) an intermediate or associative phase and c) a final or autonomous phase. Schneider and Shiffrin (1977) also suggested a similar model but using different terminology. Anderson (1982) referred to these phases as a) a declarative stage, b) knowledge compilation and c) a procedural stage. Although various terminologies have been used to clarify the concept of skill acquisition, they are similar in their underlying assumptions. In summary, in the early phase of skill acquisition there will be a potential demand on the cognitive-attentional system to understand and perform the task. With trial and error approaches, strategies are developed and tested during practice. In the second phase, the relationship between strategies and outcomes of the task is refined and strengthened, ie individuals tend to produce fewer errors and perform more precisely. With consistent practice, the task can be completed with less demand on the cognitive-attentional system so individuals would be expected to complete the task more quickly.

In the current literature, several significant factors have been identified that relate to skill acquisition. These tend to fall into two categories: a) internal factors, eg individual differences in motivational determinants (Kanfer and Ackerman, 1989; Langan-Fox et al., 2002), ability (Ackerman, 1988; Ackerman, 1990; Ackerman, 1992) and motor learning parameters (Schmidt and Lee, 2005) and b) external factors, eg the practice environment (Sohn et al., 2006). The following discussion will focus on the role of these factors using studies that have investigated them in different disciplines. Section 1.4.1 discusses the relationship between motivation and performance. Section 1.4.2 discusses the theoretical relationship between ability and performance as well as instruments used to assess ability. This section also discusses the relationship between ability and performance in dentistry. Section 1.4.3 discusses motor learning parameters that relate to variable performance. Finally, Section 1.4.4 discusses the influence of the practice environment on skill learning.

1.4.1 The motivation - performance relationship

Motivation, which is defined as ‘effort’ allocated to tasks, has been shown to influence skill acquisition (Yeo and Neal, 2004). In addition, motivation has also been shown to affect the relationship between ability and performance (Kanfer and Ackerman, 1989). Motor performance has been shown to be influenced by several factors (Kanfer and Ackerman, 1989; Langan-Fox et al., 2002) related to individual differences in motivational determinants (Kanfer and Ackerman, 1989). For example, Langan-Fox et al (2002) pointed out that an individual’s internal processes and experiences can have an important effect on motor performance. Motivation is one aspect of a learner's internal processes and characteristics which can influence motor performance. It has been suggested that individuals who display high effort tend to achieve a high level of performance (Kanfer and Ackerman, 1989; Yeo and Neal, 2004).

Cognitive effort, as a dynamic construct, plays an important role in motivation theory. Theoretically, decisions for effort allocation are influenced by two processes, the goal-orientation phase and self-regulatory processes (Kanfer and Ackerman, 1989). The goal setting phase involves intentions and choices that will be devoted to various tasks and this is influenced by factors such as task complexity and self-efficacy. When individuals set their own goals, those with high self-efficacy set higher goals than do those with lower self-efficacy (Kanfer and Ackerman, 1989; Locke and Latham, 2002). Self-regulatory processes are used by individuals to compare actual performance with a desired goal, resulting in adjustment of cognitive effort in response to the amount of cognitive effort needed to achieve a desired goal (Yeo and Neal, 2008). For instance, when individuals were confronted with a difficult task, those with high self-efficacy tended to be more committed to their assigned goal and they also used better task strategies to achieve the goals (Yeo and Neal, 2008). With feedback given during practice, they appreciated the discrepancy between their actual progress and their desired goal and this led to adjustment of effort levels or strategies to attain the goal (Locke and Latham, 2002). Kanfer and Ackerman (1989) also found that the role of ability in determining performance was affected by the level of motivation. The assignment of task goals after the initial stage of skill acquisition is thought to provide greater benefits for low-ability individuals than for high-ability individuals (Kanfer and Ackerman, 1989). Despite the key role of motivation and effort in the achievement of high quality motor performance, this issue has not been investigated in relation to either motor performance or motor learning in dentistry.

1.4.2 Ability - performance relationship

Ability is another key construct that plays an important role in learning and acquiring skills. Ability refers to the capability underlying or supporting performance in tasks (Schmidt and Lee, 2005). According to ability-relationship theory (Ackerman and Cianciolo, 2000), there are three major abilities required in each phase of skill acquisition. These are described by Fitts and Posner (1967) and are shown in Figure 1.1. In the cognitive phase, cognitive ability (including general intelligence and verbal, numerical and spatial content abilities) is required to understand the procedures associated with a particular task. In the associative phase, perceptual speed ability is required to find the most effective way to achieve the task. Consequently, after repetitively practising a particular task, in the autonomous phase learners can then perform skills through an autonomous processing system with a reduced reliance of their cognitive ability. As a result, performance in this phase is dominated by psychomotor ability (Ackerman, 1988).

NOTE:
This figure is included on page 12 of the print copy of the thesis held in the University of Adelaide Library.

Figure 1.1 Relationship between individual ability and skill acquisition phases (Ackerman and Cianciolo, 2000)

Note: In the cognitive phase (a: Phase 1), it is proposed that performance is influenced by general ability (g) including spatial, verbal and numerical content and this correlation will diminish with practice. In the associative phase (a: Phase 2), the effect of general ability on performance will decrease while perceptual speed ability will have a high correlation with performance. This correlation will decrease with repetitive practice and then the performance level will be dominated by psychomotor ability in the autonomous phase (a: Phase 3).

1.4.2.1 The assessment of cognitive ability

Cognitive ability is classified into two types, general ability and broad content ability. General ability or general intelligence refers to the ‘broad construct that underlies nonspecific information-processing efficacy’ (Ackerman, 1988), eg stimulus apprehension, generalisation, thinking, inductive and deductive reasoning and problem solving (Sternberg and Grigorenko, 2002). This ability has been investigated in psychology (Ackerman, 1988; Sohn et al., 2006) and surgery (Keehner et al., 2006) by using psychometric tests such as Raven’s Advanced Progressive Matrices. In relation to dentistry, this ability would be involved with the understanding of theoretical knowledge that underpins an operative task.

Broad content ability is an intellectual construct related to numerical, verbal and spatial ability (Ackerman and Cianciolo, 2000). Spatial ability in relation to visualization represents the capability of manipulating three-dimensional visual objects in two-dimensional imagery (Wanzel et al., 2003). This ability has been shown to be associated with superior performance in laparoscopic surgery where surgeons use images transmitted from an abdominal cavity to guide surgical procedures at operative sites (Risucci, 2002; Wanzel et al., 2003; Keehner et al., 2004). In dentistry, one might expect that this ability would be closely related to the ability needed for relevant psychomotor skills. For example, in dental practice, this ability might be required to acquire the skills needed to cut a cavity preparation in an upper tooth for subsequent restoration using indirect vision via a mirror. Three-dimensional perception and depth perception are both needed to perform this type of task.

1.4.2.2 The assessment of perceptual speed ability

Perceptual speed (PS) ability refers to "the rapidity of consistent encoding and comparisons of symbols" (Ackerman, 1988). This ability plays an important role in relation to the speed with which information can be processed. It has been shown that this ability determines performance efficiency in the second phase of skill acquisition (Figure 1.1) (Ackerman and Cianciolo, 2000). Ackerman and Cianciolo (2000) investigated the construct of perceptual speed ability using various types of tests. The results showed that this ability consisted of several factors, namely PS-pattern recognition, PS-scanning and PS-memory. As a result, it is important to make an appropriate choice of PS measures for predicting performance. In relation to dental practice, PS-pattern recognition might be a factor needed for evaluating cavity outlines and shapes, eg the shape of proximal boxes in a Class II cavity preparation. PS-scanning might be required for reviewing a cavity during preparation. Furthermore, PS-memory might be a factor required in identifying an inappropriate design of cavity preparation in relation to angulations or shapes of the cavity and in memorising a more appropriate design. As a result, PS-memory can provide a mental template for producing the same task in further practice.

1.4.2.3 The assessment of psychomotor ability

Psychomotor ability can be assessed by the speed with which individuals respond to test items with little or no cognitive processing demand (Ackerman, 1988). Tests used in several studies, eg a waxing test (Walcott et al., 1986) and a block carving test (Gansky et al., 2004) have been designed to assess this ability. The results showed a positive correlation of scores obtained in these tests with performance in preclinical dentistry. However, these tests do not appear to have been validated for assessing psychomotor ability (Ackerman and Cianciolo, 2000). According to the definition of this ability by Ackerman (1988), it appears that cognitive processing would be required to perform these tests of wax or block carving and, therefore, they do not specifically assess psychomotor ability alone. Theoretically, psychomotor ability can be measured in many ways, such as through fine manipulative abilities (Gagne and Fleishman, 1959). It has been assessed using a finger dexterity test in dentistry (Boyle and Santelli, 1986; de Andres et al., 2004) and also in surgery (Francis et al., 2001; Wanzel et al., 2003), and the scores in this finger dexterity test were positively correlated with performance (Boyle and Santelli, 1986; Francis et al., 2001; Wanzel et al., 2003; de Andres et al., 2004).

1.4.2.4 Prediction of performance in dentistry

According to the theory of ability determinants of skilled performance, the assessment of ability has been used as part of selection procedures for candidates in health professional programs, eg surgery (Gallagher et al., 2009). Due to the limited resources available for surgical training, emphasis has been placed on the selection of candidates into training programs. Many studies have investigated the use of various psychometric tests to predict technical competence in surgery (Harris et al., 1994; Francis et al., 2001; Risucci, 2002; Wanzel et al., 2003). Surgical novices with higher-level visual-spatial ability displayed positive correlations with total scores from the first and last trials of a laparoscopic simulation task (Hedman et al., 2006). Likewise, Keehner et al (2006) found that in an initial learning trial, inter-individual variability in performance on a virtual angled laparoscopic task was influenced by general and spatial ability. Despite inter-individual differences in general and spatial ability, students in the lower-ability group demonstrated proficiency in the task but only spatial ability remained as being significantly associated with performance in the last trial. These findings are consistent with the theory of skill acquisition (Ackerman, 1988) where the relationship between ability and performance vary based on content-based tasks (see details information in section 1.4.2.5). While general ability shows a strong correlation with performance in the initial learning phase and diminishes in later stages of learning, spatial ability is correlated persistently with performance even after skills have been acquired.

A number of studies have focused on identifying a selection instrument that can be used to predict applicants' performance in dental programs (Spratley, 1990). Tests that have been used include cognitive ability tests, eg the Dental Admission Test (DAT), manual dexterity tests, eg chalk or wax carving, and interviews. The use of these tests varies between institutions and countries but all have similar basic elements. Many studies have explored the value of the different types of selection tests, in particular cognitive ability admission tests and manual dexterity tests, in predicting future performance in dental preclinical courses (Boyle and Santelli, 1986; Kramer, 1986; Walcott et al., 1986; Luck et al., 2000; Gillet et al., 2002; Gansky et al., 2004). However, the existing findings are conflicting. The U.S. Perceptual Ability Test (PAT), which consists of five subtests in relation to spatial content in cognitive ability, has been found to be positively correlated with grades in preclinical operative courses in first year (Kramer, 1986; Walcott et al., 1986; Gansky et al., 2004). Other studies have also found a strong association between manual dexterity (which is one component of psychomotor ability) and grades for preclinical laboratory courses (Boyle and Santelli, 1986; Luck et al., 2000; Gillet et al., 2002; Gansky et al., 2004). The manual dexterity tests used in these studies include the Crawford Small Parts Dexterity test (Boyle and Santelli, 1986) and making a cavity in a resin tooth (Gillet et al., 2002) using a drill. As the values of correlation coefficients reported in these correlation studies only ranged from 0.1 – 0.5, it has been suggested that scores obtained for the Perceptual Ability Test or manual dexterity tests can only be used for screening rather than as predictive tools (Ranney et al., 2005).

In addition to the use of the tests noted above, there is an increasing trend to use well-validated and objective methods of assessment, eg in surgery. For instance, in laparoscopic surgery, a virtual-reality laparoscopic simulator was used to assess the skills of candidates in addition to interview sessions with senior surgeons (Salgado et al., 2009). Not surprisingly, no positive correlation was found between the results of simulation training and interview scores by the senior surgeons. In contrast, one study showed that a virtual reality simulator could be used to determine expert performance in dentistry (Wierinck et al., 2007). In this study, experts in operative dentistry outperformed experts in periodontology and dental students in preparing a Class II cavity preparation. Therefore, virtual reality simulations might be useful in providing additional information for selection procedures, but further research is needed.

1.4.2.5 Ability - performance relationship in dentistry

Several studies have considered the relationship between ability and motor performance in particular skills, including surgery (Keehner et al., 2006) and dentistry (Gray and Deem, 2002; Gray et al., 2002). A significant relationship was noted between the level of cognitive ability and performance in laparoscopic simulation (Keehner et al., 2006). The results are consistent with the theory that the relationship between individual differences in abilities and performance will still be significant even after practice. In other words, specific ability is required to acquire a particular skill(s) in tasks. This means that students who have the high level of ability that is needed in dentistry, should also demonstrate a high level of dental psychomotor performance. From this relationship, it is clear that examination of these abilities could be beneficial in predicting future motor performance needed for particular skills (Ackerman, 1988; Ackerman and Cianciolo, 2000). As a result, scores from ability tests have been reported to provide useful information when recruiting dental students (Kramer, 1986; Oudshoorn, 2003) and surgeon trainees (Anastakis et al., 2000).

The outcomes of tests used to assess cognitive ability in previous dental studies (Walcott et al., 1986; Gillet et al., 2002; de Andres et al., 2004) do not appear to be consistent with the findings of Keehner et al (2006). Specifically, several studies in preclinical dentistry have found no relationship between general ability as indicated by college Grade Point Average (GPA) and dental psychomotor skills in preclinical sessions (Walcott et al., 1986; Gillet et al., 2002; de Andres et al., 2004). It has been noted that college GPA was significantly associated with academic performance in dental school (Boyle and Santelli, 1986; Sandow et al., 2002) but it was not associated with performance in preclinical courses (Boyle and Santelli, 1986; Walcott et al., 1986; Gansky et al., 2004). However, grades are not considered to directly reflect the learning parameters required in skill acquisition (Schmidt and Lee, 2005). It appears that, in this context, GPA represents the comprehensive measurement of the capability of acquiring basic knowledge. As a result, GPA might not be an adequate test of cognitive ability in terms of providing specific information about which parameters are needed for acquiring psychomotor skills in dentistry.

Several studies have investigated the predictive value of a visual spatial ability test, namely the Perceptual Aptitude Test (PAT), in relation to dental performance in preclinical operative courses (Kramer, 1986; Oudshoorn, 2003; Gansky et al., 2004). However, the results again have been inconsistent. While some studies (Oudshoorn, 2003; Gansky et al., 2004) have shown that the values of regression coefficients of total PAT scores in predicting dental performance are low, others have found that subtest scores for manipulating three-dimensional objects, eg orthographic projections, apertures and form development, can predict dental performance effectively (Kramer, 1986). Heintze et al (2004) also found a positive relationship between results in a preclinical operative course and scores on a spatial ability test. In their study, spatial ability was measured by asking examinees to visualise a three-dimensional object when given various two dimensional views. The test appears to be similar to what has been used in PAT.

These conflicting results may be explained by the fact that visual spatial ability can be classified into five categories (Wanzel et al., 2003). Mental visualisation represents a high-level category of visual spatial ability. A test of this ability, the Mental Rotation Test (MRT), has been used in studies that have shown a positive correlation between mental visualisation and surgical skills (Wanzel et al., 2003; Keehner et al., 2006). This test involves manipulating the visual imagery of two-dimensional and three-dimensional objects in different configurations. In relation to dental practice, for example completing a cavity preparation, a high level of visual spatial ability is likely to be required to manipulate two-dimensional images as reflections in a mouth mirror. In addition, this ability may also be required to visualise three-dimensional relationships in a prepared cavity. However, very little is known about the relationship between scores from the MRT and the acquisition of psychomotor skills in dentistry.

Psychomotor ability tests can also be used to identify students who might have a low level of dental psychomotor skills (de Andres et al., 2004). In these studies, marks obtained from a test of practical activities and tutor evaluation, (de Andres et al., 2004) or preclinical technique course grades (Boyle and Santelli, 1986) were used to represent motor performance in preclinical dentistry. However, these variables were not explicitly validated to represent the specific motor performance of interest. As the study by de Andres et al (2004) did not indicate how practical marks had been evaluated and how practical marks were validated, the reliability of the results is questionable.

In summary, the relationships between the three abilities noted in skill acquisition theory (Ackerman and Cianciolo, 2000) and performance have been investigated in dentistry. While the majority of studies have investigated the influence of cognitive ability and psychomotor ability on dental performance, as discussed earlier, little information is available for the relationship between perceptual speed ability and performance in dentistry. Various instruments have been used to determine these relationships, as discussed previously, but the results are not consistent. It is possible that the lack of consistent results in previous studies might be due to a lack of explicit integration of theory to inform the selection of ability tests. Ackerman and Cianciolo (2000) state that it is important to select appropriate ability tests that have key elements of the task(s) under investigation and to validate collected data. It appears that up until now ability tests in dentistry have been used without first validating them based on theory.

1.4.3 Motor learning parameters and performance

As noted in section 1.4, the final aspects of internal factors that influence skill acquisition are motor learning parameters. Motor learning has been studied widely in sport and surgical training. Several motor learning theories have focused on the development of memory representation of skills acquired from learning, eg the closed-loop theory (Adams, 1971) and Schema theory (Schmidt, 1975). These theories place an emphasis on movement guided by feedback which is the result of comparing memory representation and ongoing movement. Schema theory has been used to explain how individuals can perform movements and how individuals develop effective performance with practice (Schmidt and Lee, 2005). As discussed by Schmidt and Lee (2005), the key concept of this theory involves three features, ie a generalised motor program (GMP) and two types of independent memory states, ie recall schema and response recognition schema. The generalised motor program is responsible for preparation of movement in advance and it plays an important role in a fast-movement task that has the limitation of using feedback to guide movement, eg throwing a ball. It would appear that this feature might not be able to solely describe how psychomotor skills in surgery or dentistry are learned, as the skills involve continuous rather than discreet movement. Recall schema involves initiating movement in response to the selection of parameters needed for achieving the task. For instance, with practice individuals would determine movement patterns that enable them to accomplish the goal of the task. Subsequently, they would generate and apply those movement patterns to the generalised motor program. Finally, response recognition schema relates to identifying errors during or after completion of a movement. It involves comparison of expected sensory consequences with actual outcomes. Expected sensory consequences are generated and moderated when individuals initiate movement and associate the sensory consequences of the movement with outcomes.

Application of the knowledge of these underpinning features in Schema theory has resulted in positive effects on acquiring skills in athletic training (Smith and Taylor, 1997) and physical therapy (Rice and Hernandez, 2006). It has been shown that providing an appropriate training program focused on relevant parameters in motor learning can enhance effective learning of skills (Schmidt and Lee, 2005). In dentistry, several studies have found that students can learn to perform at a higher level by integrating these parameters into the design of preclinical activities (Feil et al., 1986; Feil and Reed, 1988). For example, Feil (1989) applied the fundamental concept of motor learning theory in dental practice by addressing four key parameters in Schema theory, ie desired outcome, desired performance, knowledge of results, and knowledge of performance. The definitions of these parameters are provided in Table 1.2. Desired outcome and performance refer to knowledge of what the expected outcomes and processes need to be. These two parameters are related to recall schema as they specify the movement required to complete a task. Knowledge of results is defined as feedback received after completing movement and about errors in relation to actual outcomes, while knowledge of performance refers to feedback information about discrepancies between desired performance and actual performance. These two types of feedback can be from self-evaluation or external sources, ie from learners or trainers. This feedback is needed to plan and modify movement in subsequent trials and to achieve more accurate outcomes and performance. Knowledge of results and knowledge of performance would seem to be consistent with a response recognition schema as they are involved with evaluation procedures in relation to outcomes and movement as discussed previously.

Table 1.2 Definitions of motor learning parameters

Motor learning parameters	Definitions
Desired outcome (DO)	Knowledge of what is to be achieved either in verbal or visual representation
Desired performance (DP)	Knowledge of what procedure (s) need to be performed to achieve DO
Knowledge of results (KR)	Knowledge formulated by comparing the actual outcome and DO
Knowledge of performance (KP)	Knowledge about error information formulated by comparing the actual performance and DP

A series of studies has investigated how these four parameters can enhance learning of skills in dentistry (Feil et al., 1986; Feil and Reed, 1988; Feil, 1992; Feil and Gatti, 1993; Feil et al., 1994; Knight et al., 1994; Guenzel et al., 1995a; Guenzel et al., 1995b). Outcomes of these studies indicated that students' performance was improved when they were provided with continuous knowledge of results (Feil et al., 1986). This study suggested that students need to practise evaluation of their outcomes using a checklist of criteria and also to discriminate between outcomes of different quality. It appears that the activities provided in this study would have helped students to develop knowledge of results and to identify errors of their outcomes more accurately. As identification of errors in outcomes is needed to modify movement to achieve desired outcomes (Schmidt and Lee, 2005), these activities should lead to better performance in operative dentistry. Consequently, a series of studies has been published that describe the implications of these findings in the design of preclinical laboratory instruction (Feil et al., 1994; Knight et al., 1994; Guenzel et al., 1995a; Guenzel et al., 1995b). Guenzel et al (1995a) suggested how instructional tasks can be developed with practical sequences of procedures. For instance, as discrimination training methods have demonstrated significant promise in improving student performance (Feil et al., 1986), this method should be integrated into instructional design to enable students to recognise deficiencies between their actual and desired outcomes (Guenzel et al., 1995a). It appears that discrimination training methods assist students to develop visual representations of desired outcomes.

To better understand how individuals manipulate learning parameters during a task, an understanding of individual cognitive information-processing systems is needed. A method that can identify this implicit process provides a potential strategy for understanding how individuals apply learning parameters to achieve an expected outcome. The think-aloud technique is a procedure used for cognitive assessment and this method can be used to gain access to how people think by collecting their own comments about their performance (Nielsen et al., 2002). In dentistry, one study has used this retrospective method to identify the learning parameters used in a dental task involving both experienced practitioners and dental students (Feil and Gatti, 1993). The results showed that there was a significant difference in visualisation of cavity preparations between the two groups. However, these data were drawn from verbal self-reports that were obtained in the subsequent two-week period after performing the task, and therefore they may not be reliable. Indeed, a substantial factor in using a retrospective approach that influences the accuracy of verbalisation, is short-term memory (Nielsen et al., 2002). The length of time that has elapsed after completing a task may influence the accuracy of short-term memory. In other words, subjects might not remember what they were thinking at a particular time during the task. Further investigation of learning experiences in dentistry using this technique is needed.

As noted previously, to understand how individuals learn a new skill, it is important to investigate both motor performance and motor learning aspects. There are several theories proposed to explain the science of motor or movement learning, eg Adams' closed loop theory, Schmidt's schema theory and ecological theory. Each theory has its own limitations in explaining what occurs when an individual is trying to learn new skills (Rose and Christina, 2006). Schema theory has received a great deal of attention from researchers for many decades. Recently, Schema theory has been revised and its deficiencies have been widely discussed, as the latest findings have not been consistent with the theory (Sherwood and Lee, 2003). For instance, this theory cannot be used to explain how people are able to learn by observation without having cutaneous sensory feedback or movement (Rose and Christina, 2006). Despite recent studies highlighting some limitations of Schema theory, the current study used this theory to inform the design of the research methods as it is potentially related to the contexts of skill learning in dentistry. Indeed, recent studies in dentistry (Wierinck et al., 2005; Wierinck et al., 2006), indicate that parameters addressed in this theory remain relevant to skill learning.

1.4.4 Practice environment and performance

The final factor that has been reported to influence performance but is external to the learner is organisation of the practice environment, eg the practice schedule (Rose and Christina, 2006). The practice schedule refers to how practice activities are arranged, eg in relation to the frequency and sequence of task components. Aspects of the practice environment have been investigated in previous studies involving surgical training (Dubrowski et al., 2005; Brydges et al., 2007). One external factor, the practice schedule, has been identified to be a key component for enhancing skill acquisition following investigation of the optimum practice schedule for training surgical trainees (Dubrowski et al., 2005; Brydges et al., 2007). In these studies, different practice schedules based on variable sequences and organisation of complex surgical tasks were analysed for their effectiveness in enhancing skill learning. The schedules included whole practice, partial-blocked and partial-random practice. For example, surgical tasks can be taught for an entire task, referred to as whole practice, in which learners work through the whole task in sequence. Fundamental elements can also be taught separately. For instance, for a bone plating task that can be divided into several elements, eg drilling of screws and depth measurement, the task can be taught with several trials of the same element as a blocked practice or with a random order of the elements as a random practice (Dubrowski, 2005). In the study of Dubrowski et al (2005) and Brydges et al (2007), a whole practice schedule was found to be a more effective training method as it could enhance learning of bone plating skills. The results showed differences in performance and skill learning of trainees due to different practice schedules, leading to the identification of specific learning activities that supported development of satisfactory processes and outcomes for the specific surgical procedures. In contrast, a recent study explored different factors that influence learning of technical skills in an endoscopy training program (Thuraisingam et al., 2006), with emphasis on the segmentation of practice on skills learning. The researchers showed that practising simple components of a complex task was beneficial to learning of the skills (Thuraisingam et al., 2006). The study by Thuraisingam et al (2006) did not investigate whether learning outcomes matched with participants' learning experiences such that little information is known about actual participants' performance in the program. Given the conflicting results of these previous studies and that there are no published reports on similar studies in dentistry, little is known about various practice schedules and their effect on performance in dentistry.

Information about students' perceptions of the learning environment can provide insights for students and also educators. A course evaluation process can be used to clarify strengths and weaknesses of a course or practice schedule that students have completed (Henzi et al., 2007). Research has shown that students' perceptions of their learning context, eg what is required of them in the learning tasks/assessment, is a critical element in the approaches they adopt for learning and the resultant quality of their learning outcomes (Biggs, 2003; Prosser and Trigwell, 1999; Ramsden, 2003). Therefore, an understanding of students' perceptions of their practice schedules is needed to assist in our understanding of effective and ineffective learning experiences. However, studies by Dubrowski et al (2005) and Brydges et al (2007) did not provide information about students' perceptions of their learning experiences particularly related to the practice schedule. For example, a recent study using qualitative methods investigated students' perceptions of learning experiences in a dental school as a part of a curriculum review (Victoroff and Hogan, 2006). In this study, students' experiences in didactic, preclinical and clinical components were examined. The results indicated several activities, based on the students' understandings, that could be implemented to improve learning outcomes. However, it was not clear whether these data were collected during, or in close proximity to the relevant learning activities. Moreover, the researchers did not explicitly use a theoretical framework to inform questions used in the interview sessions.

1.5 Rationale for the study

As noted above, several significant factors have been identified that influence skill acquisition. These tend to fall into two categories: a) internal factors, eg individual differences in motivational determinants, ability and motor learning parameters and b) external factors, eg the practice environment. Due to the influence of individual differences in motivation and effort (Kanfer and Ackerman, 1989; Yeo and Neal, 2004) and also the three abilities associated with skill acquisition theory (Ackerman, 1988) on motor performance, dental students are likely to display varying capacities in acquiring psychomotor skills within the constrained period of preclinical learning. Furthermore, the ability-performance relationship has been shown to validate the application of the skill acquisition model in learning dental clinical skills (Gray and Deem, 2002; Gray et al., 2002). This relationship has also been used to predict future performance and assess the mastery of dental psychomotor skills (Walcott et al., 1986; Oudshoorn, 2003; de Andres et al., 2004; Gansky et al., 2004). However, previous researchers in dental education who have investigated the ability-performance relationship have often not explicitly integrated theory-based approaches in their studies, which may have contributed to inconsistent findings. As a result, the usefulness of findings from past studies is limited by a) a lack of explicit theoretical justification for the ability tests used, b) a lack of investigation of all abilities and motivational determinants related to skill acquisition, and c) a lack of identification of a specific motor performance to be assessed. In addition, while many studies have investigated the acquisition of psychomotor skills in dental students in terms of the prediction of performance, only limited information is available on motor learning aspects. This includes motor learning parameters developed through skill practice and learning experiences during practice in the acquisition phase (Feil and Gatti, 1993). Moreover, little information is available about the relationships between various factors associated with skill learning in dentistry. Furthermore, there is limited published information regarding dental students' understanding and experience of psychomotor skills practice schedules.

As noted previously, psychomotor skills in dental education have mainly been assessed in terms of motor performance and outcomes, without consideration of other influential factors on performance. An assessment of the outcomes of motor performance only reflects the final product of learning but does not provide critical information on how students achieve the outcome, ie their learning processes. Information on learning processes could be used to inform the design of effective learning activities and studies with a longitudinal design could be particularly valuable. A theory-based approach, using validated and reliable tests of the abilities associated with each phase of skill acquisition, is needed for assessing motor performance. Furthermore, studies of the effect of motivation on motor performance would provide a broader perspective on the assessment of psychomotor skills. Identification of individual differences in the use of motor learning parameters is also needed to improve understanding about the motor learning aspects of skill acquisition and, hopefully, to enhance dental educators' understanding of how students learn. In addition, exploratory studies are needed to clarify students' perceptions of their learning experiences during practice, as this should inform dental educators about the characteristics of practice environments that can promote positive learning experiences.

1.6 Research questions

To clarify potential differences in skill learning in students with variable performance, the current study aims to answer the following research questions:

- What is the relationship between dental motor performance and
  a) motivational determinants?
  b) cognitive ability?
  c) perceptual speed ability?
  d) psychomotor ability?

e) key motor learning parameters, ie desired outcome, desired performance, knowledge of results and knowledge of performance?

The current study aims to investigate factors that influence learning of psychomotor skills by dental students in terms of both outcomes and processes. As stated previously, motivation (see section 1.4.1) and ability (see section 1.4.2) are key factors in skill acquisition. Specifically, individuals tend to modify the effort that they allocate to a task in relation to the level of cognitive-processing demands of the task. Research question a) enables testing of the hypothesis that those students who apply high levels of effort should show a higher level of dental performance. In addition, the identification of ability-performance relationships should help to inform educators about individual differences in learning psychomotor skills in dentistry. This would provide insights into understanding which key abilities are required in learning dental skills. Students who demonstrate higher levels of certain abilities would be expected to show better learning outcomes and better understanding of these issues should assist in identifying students who might have difficulty in learning skills. Furthermore, research question e) should help us understand the motor learning parameters (see section 1.4.3) that students use as learning processes during completion of a dental task. As a result, the findings should be useful in informing the design of learning activities to optimise outcomes.

To clarify how the practice environment influences learning of skills (see section 1.4.4), the second main research question is as follows:

- What learning activities do students perceive are effective or ineffective in supporting their learning?

In addition to the identification of internal factors, eg motivation, ability and the use of motor learning parameters, this research question aims to improve our understanding of students' perceptions of current approaches in a dental program. It should also provide useful information to inform the design of an effective curriculum for enhancing skill learning. Although identification of appropriate practice schedules for learning psychomotor skills in dentistry is needed, this aspect is beyond the scope of the current study. As the study was conducted during normal classes (see details in Chapter 2), it was not possible to undertake a comparative study.

The subsequent chapters in this dissertation are organised into three main sections, ie research methods, results of the study and discussion of the results. Chapters 2 and 3 provide information about the research methods and instruments used in the current study as well as the properties of those instruments in terms of their validity. To address the research questions, the current study used both quantitative and qualitative approaches. Chapters 4, 5 and 6 present results relating to the research questions noted previously. It is planned to prepare three papers for publication based on the findings presented in Chapters 4, 5 and 6. The final chapter provides a discussion of the results and implications for practice. This is followed by a list of references and then a list of achievements during the PhD candidature (Appendix 1), together with other Appendices.

Chapter 2 - Methods

Details about the research design and techniques used to address the two main research topics of this thesis; ie 1) factors that influence skill learning, and 2) students' perceptions of effective and ineffective learning experiences, are provided in this chapter. Firstly, an overview of the research design and recruitment procedures will be provided. Then, a description of the sample and context of the skill learning environment will be provided, prior to a more detailed consideration of the methods employed.

2.1 Research design

To investigate how novices learn a new skill, studies have traditionally been conducted at the time the novices are initially confronted with a task (Ackerman, 1988; Keehner et al., 2006). A dependent variable, eg outcomes or performance, then needs to be defined and assessed (Rose and Christina, 2006). This is followed by an observational study and recording of the findings for the dependent variable(s).

To address the research questions (see Chapter 1, Section 1.6) about activities that support learning of skills, the current study was conducted in a naturalistic setting based on students' actual experience within their usual classes. The candidate enrolled initially in a two-year Master of Science in Dentistry degree in 2006 and data were already available from cavity preparations completed by third-year students (2007) when they were in second year (2006). Therefore, the study involved third-year students in the first instance, and this aspect, referred to as Phase I, particularly addresses research questions related to internal factors namely, motivation, ability and motor learning parameters, and performance (Figure 2.1). Specifically, students completed psychomotor tests prior to completing written and cavity preparation exercises. Immediately after these exercises, they completed a survey about their motivation during the preceding operative activity. Sub-groups of students were also observed and interviewed regarding the thinking they used during their cavity preparations.

As a significant association between ability and dental performance was found in Phase I and the Masters program was converted to a PhD, a longitudinal study, was then conducted involving second-year students (2008). This component of the study is referred to as Phase II and it involved integration of broader aspects of skill learning, including external factors related to students' experiences of the practice environment (Figure 2.1). In summary, students completed the same activities as for Phase 1, but data were collected at different times throughout the academic year. These data were supplemented with observation and outcome data from laboratory exercises, critical incidents, and interviews completed at various times in the academic year. Detailed information about the two phases of the current study is provided below.

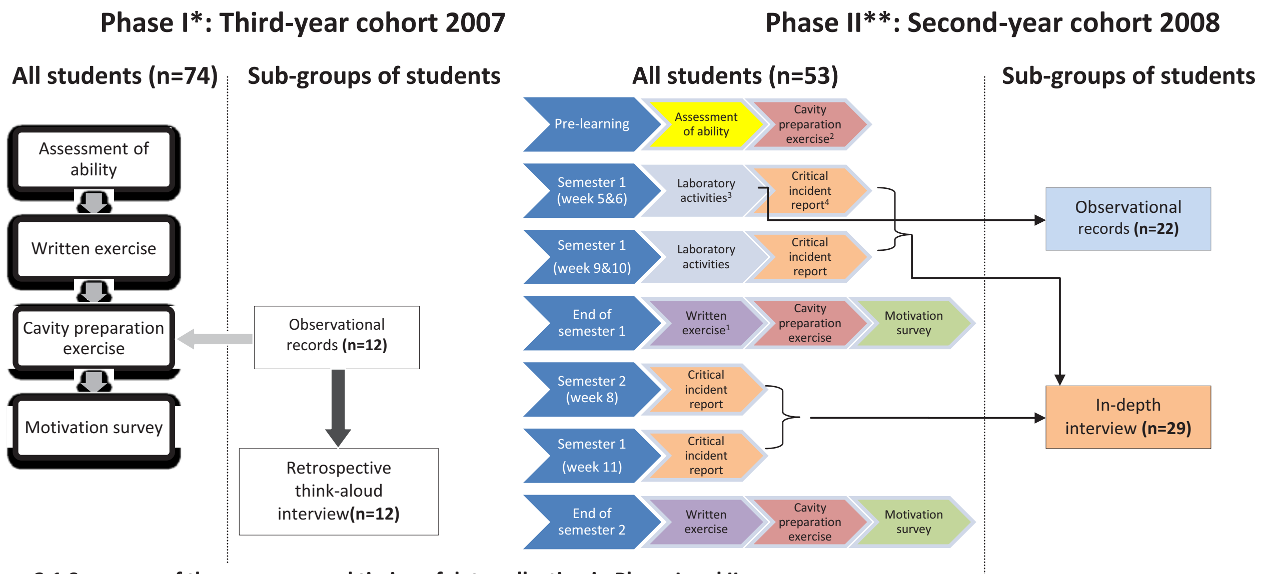


Figure 2.1 Summary of the sequence and timing of data collection in Phase I and II

Note: *In Phase I, psychometric tests were used to assess three abilities (section 2.3.1) at the commencement of the DCP 3 course. Written exercises were used to assess theoretical knowledge about an MOD cavity preparation for amalgam (section 2.3.2). Students then completed a cavity preparation within 30 minutes (section 2.3.3), followed immediately by a motivation survey (section 2.3.4). During preparation of the cavity, time spent in each action during the task by two sub-groups of students was recorded (section 2.3.5). They were also videoed to enable clarification of thinking processes of students in subsequent interview sessions (section 2.3.6).

**Similar datasets were also collected in Phase II of the study as shown. [1]Written exercises were conducted at the end of semester 1 and 2. [2]Students completed a cavity preparation at the pre-learning stage and end of semester 1 and 2. The motivation survey was conducted at the end of semester 1 and 2. [3]Selected groups of students were observed during the completion of exercises in four laboratory sessions (see Chapter 2, section 2.3). [4]Critical incident reports (section 2.3.7) were used to identify students' perceptions of the practice environment in four laboratory sessions. These were followed by short interviews with a subset of students which also addressed motor learning parameters.

2.1.1 Phase I of the study

To determine the nature of the relationship between individual differences in ability and motivational determinants and performance on routine operative dentistry tasks, a cross-sectional study was conducted at the commencement of the third year of the Adelaide dental program (2007), after students had completed a one-year preclinical operative technical course during second year (see details in section 2.2). It was expected that at this stage of their practice, the students would have a comprehensive understanding of both the declarative and procedural knowledge (Anderson, 1982) needed for performing a basic task related to operative dentistry. It was also expected that students would have developed motor learning parameters through completion of a range of exercises in their second year operative technical course. Therefore, Phase I also investigated the use of the motor learning parameters by students during completion of a routine operative task (Figure 2.1).

2.1.2 Phase II of the study

While individual abilities are not expected to be influenced by learning (Schmidt and Lee, 2005), to test for a possible effect, a second phase of the study investigated individual differences in a separate cohort of students at the beginning of their second year and before they had participated in their pre-clinical operative technique course. Specifically, this phase aimed to clarify whether the skills students learnt in the course influenced their performance on selected psychometric tests. This was achieved by exploring whether ability and motivational determinants contributed to changes in motor performance throughout the operative technical course (Figure 2.1). Furthermore, with a longitudinal approach, this provided an opportunity to collect increased numbers of students' cavity preparations (see section 2.3.3) to enable a correlative study to be undertaken (Figure 2.1: laboratory activities, Semester 1). This enabled information about students' learning experience and learning outcomes throughout the course to be gathered. In addition to individual factors, this phase of the study also examined external factors related to performance, ie learning experiences that students reported had influenced their skill learning, and also motor learning parameters used during performance activities (Figure 2.1: critical incidents and interviews).

2.1.3 Recruitment procedures

This study involved an assessment of psychomotor skill levels acquired by dental students and an assessment of how these levels related to their learning experiences. Ethical approval was obtained from the Human Research Ethics Committee of the University of Adelaide (Protocol H-154-2006). The study was designed to ensure that the following possible negative outcomes on students were minimised:

- any harm or perceived harm relating to their choice to participate or not;
- any real or perceived negative impact in relation to assessment of their performance and progress in the course as a consequence of criticisms of, or poor performance in, psychomotor skills that formed part of the project, and
- the research becoming intrusive and interfering with, or impacting on, students' participation in other aspects of their course.

The candidate coordinated the consent processes including de-identifying and coding all matching data sets for students. Specifically, students were invited by the candidate to participate in the study and were provided with an information sheet and consent forms. The candidate collected the signed consent forms and stored them securely. Student consent forms were used to identify data for consenting students while data from students who had chosen not to participate were removed and shredded by the candidate.

2.1.4 Description of participants in Phase I

Participants in Phase I were third-year dental students enrolled in the Adelaide School of Dentistry during 2007. They are referred to as the 'third-year cohort'. This cohort had completed 24 weeks of preclinical operative exercises as part of Dental Clinical Practice 2 (DCP 2), a second-year course involving operative dentistry. In addition, they also completed 3-4 weeks of preclinical operative exercises as part of Dental Clinical Practice 3 (DCP 3), a third-year course that includes the clinical management of patients (see the structure of the Adelaide Bachelor of Dental Surgery program in Appendix 2).

2.1.5 Description of participants in Phase II

Participants in Phase II were second-year dental students in 2008 and they are referred to as the 'second-year cohort'. This cohort of students had not yet commenced any preclinical technical exercises in the Adelaide dental program.

2.1.6 Inclusion and exclusion criteria

Participants in both phases of the study were drawn from consenting students based on the following exclusion and inclusion criteria:

- **Inclusion criteria**

All third- and second-year dental students were included who had consented to the use of their data derived from preclinical operative technique activities in DCP 2, had completed all relevant DCP 2 activities and had completed all tests related to this study. Specifically, these tests were:

- Psychometric tests and a motivation survey
- Written exercise (semester 1 and 2, DCP 2)
- For 2007 third-year students: cavity preparations on three teeth: lower left first molar (tooth 36) in semesters 1 and 2 of DCP 2 in 2006, and at the commencement of semester 1 in 2007
- For 2008 second-year students: cavity preparations completed in four consecutive laboratory sessions (see details in section 2.3.3), cavity preparations on three teeth: lower left first molar (tooth 36) at the commencement of semester 1, and end of semesters 1 and 2, as well as a manual dexterity exercise completed in week 2 of the DCP 2 course

Students were excluded if they had not consented to participate in this study; were absent from any of the scheduled sessions where the above data were collected; and/or did not complete all exercises; and/or were repeating the Adelaide dental program at the time when data were collected.

2.1.7 Selection of sub-groups of students

To address the research questions about how students' thinking processes relate to their performance on a task and students' perceptions of learning activities that are effective and ineffective in improving their performance (refer to Chapter 1 section 1.6), a group of students was drawn from each cohort based on specific criteria. As noted previously, differences in the use of motor learning parameters have been reported between groups with different levels of performance (Feil and Gatti, 1993) (see section 1.4.3). Therefore, the rationale for this selection was to test whether students with different levels of performance showed differences in their use of motor learning parameters during a task, and also whether their perceptions of effective and ineffective learning activities differed. As the purpose of this research design was to explore qualitatively those aspects noted above, sub-groups of students were selected (Figure 2.1) to be involved in this aspect of the study rather than the whole class (see section 2.1.7). Detailed information about the selection criteria is given below.

2.1.7.1 Sub-groups of students: Phase I: third-year cohort

Two sub-groups of students were selected representing both ends of the performance range (n=6/sub-group). These sub-groups are referred to as 'higher' and 'lower' performance sub-groups. The criteria for selecting students for these groups were based on performance in the cavity preparation exercises on the lower left first molar (tooth 36) that were completed during the second year. The higher performance sub-group included students who had obtained grades of 'Satisfactory' and/or 'Good' in semester 1 and 2, while the lower performance sub-group included students who had obtained grades of 'Unsatisfactory' and/or 'Unsatisfactory redeemable' in both semesters (see section 2.3.3 for a description of these grades). Firstly, sixteen students were identified based on the criteria and they were invited to participate in the qualitative study. Twelve students representing the ends of the performance range (n=6/ sub-group) were then selected. Two students (one from each sub-group) subsequently withdrew before the commencement of the study resulting in two remaining students being invited to participate in the study.

2.1.7.2 Sub-groups of students: Phase II: second-year cohort

For the second-year cohort, two sub-groups of participants representing both ends of the performance range (n=10-11/sub-group) were selected. These sub-groups are referred to as 'higher' and 'lower' performance sub-groups. The criteria for selection were based on their performance in the cavity preparation exercise on tooth 36 and also in a manual dexterity exercise completed at the commencement of semester 1. The manual dexterity exercise was the first class exercise when students used a high-speed rotary instrument to create specific shapes in a plastic block (see Appendix 3). This exercise is designed to introduce skills in controlling a handpiece, so it is considered to provide relevant data to identify individual capacity in learning operative skills. As for the third-year cohort, the higher performance sub-group included students who had obtained grades of 'Satisfactory' and/or 'Good', while the lower performance sub-group included students who obtained grades of 'Unsatisfactory' and/or 'Unsatisfactory redeemable' in both exercises.

2.2 Overview of the Dental Clinical Practice course

This study was conducted during operative laboratory sessions that formed one component of the Dental Clinical Practice 2 course (DCP 2) in the second year, and the Dental Clinical Practice 3 course (DCP 3) in the third year of the Adelaide BDS program (Appendix 2). These courses are designed to enhance the integration of knowledge and to build the necessary skills needed for subsequent clinical experience. In DCP 2, these skills include preventive, periodontal and simple restorative care. The restorative care domain provides basic skills that underpin more advanced procedures in prosthodontics and endodontics.

The 24-week DCP 2 course consists of a series of class meetings, operative laboratory sessions, clinic sessions and student: tutor feedback sessions (see Appendix 4). In class meetings, an interactive lecture is provided to review the knowledge related to the subsequent laboratory session. Class meetings are followed by two three-hour laboratory sessions per week that address key activities needed in operative dentistry. In addition, a three-hour clinical session is allocated to enable students to assess the dental health of their colleagues and patients and provide appropriate preventive and periodontal treatment.

At the commencement of the DCP 2 course, students are provided with a laboratory manual that presents detailed information about the key laboratory activities to be undertaken. Students also use a kit of hand instruments during these sessions, eg dental mirror and explorer. In the first week of the course, students are introduced to rotary instruments and burs, as well as seating positions and maintenance of appropriate posture whilst working. Plastic typodont teeth with full crown anatomy (Frasaco^{TM}) mounted in upper and lower arches within a phantom head are used throughout this course (Figure 2.2). The laboratory exercises and set up encourage students to practise within a simulated clinic environment. For example, the phantom head can be adjusted to simulate the head position of a real patient in the clinic.

Students are introduced to a range of exercises commencing with simple cavity preparations on the occlusal surface of teeth and moving on to more complex cavity preparations on both the occlusal and proximal surface(s). Activities include approximately 12 occlusal cavity preparation exercises (six each from upper/lower) and 20 proximal and/or combination cavity preparation exercises in the 22 laboratory sessions (see Appendix 5). The DCP 2 laboratory schedule can differ from year to year in terms of the number and the sequence of exercises allocated for each laboratory session based on an annual review by the DCP 2 course coordinator (See Appendix 6). For instance, the number of exercises involving large occlusal, slot preparation and combination cavity preparations, was increased in semester 1 of DCP 2, in 2008 compared with DCP 2 in 2006. Furthermore, in semester 2 in 2006, students were required to complete the combination cavity preparation exercises on posterior teeth (week 3 – week 5), and this was followed by cavity preparations on anterior teeth (week 6 – week 9). In contrast, in semester 2 in 2008, students initially completed cavity preparations on anterior teeth (week 3 – week 4), and then completed various exercises including the combination cavity preparation exercises according to a clinical scenario that was provided (week 5 – week 9).

a) b)

Figure 2.2 Illustration of a) plastic typodont teeth with full crown anatomy (Frasaco^{TM}) mounted in upper and lower arches and b) Frasaco^{TM} models mounted in a phantom head

Several activities are conducted routinely in each laboratory session. At the commencement of a session, the coordinator of the DCP 2 course reviews the procedures and required outcomes of the task using PowerPoint presentations that have been discussed in class meetings and also provided online to students prior to the laboratory sessions. Subsequently, students begin working on the assigned laboratory activity for the session, following the procedures outlined in the DCP 2 laboratory manual. Groups of 8-10 students practise under the supervision of a tutor who is a member of the academic staff or a part-time sessional clinical tutor, who may work in private practice or be studying in a clinical postgraduate program. The tutors use a range of methods to facilitate learning of skills during these sessions. For example, prior to the start of an exercise, tutors may preview the assigned exercise, including instrumentation and/or the expected outcome. Some tutors use visual aids to help students understand the task in each particular session. There will be some differences in learning contexts from year to year in terms of tutors, course materials and teaching approaches. During a session, tutors provide formative feedback as requested by students. At the end of a session, students complete a self-assessment form (see Appendix 7) and discuss their performance with their tutor. The assessment criteria used are the same as for those used for clinical assessment across all year levels of DCP, namely knowledge base, skills, patient management and professional behavior (Wetherell et al., 1999).

The concept of minimal intervention is introduced to students in the DCP 2 course, as well as GV Black's principles, particularly in relation to removing caries and cavity design (see examples in Appendix 8). Table 2.1 shows differences in cavity preparation design between classic GV Black and a modified version of the GV Black approach used in this course. As plastic typodont teeth do not have simulated carious lesions, students are required to cut cavities according to the modified GV Black concepts for cavity design. In general, a cavity is prepared with minimal invasive cutting of tooth structure and also the design of the cavity is focused on the functionality of subsequent restorative materials. For example, with the advanced properties of restorative materials, eg adhesive chemical agents, a definite line or point angle is not needed to gain retention for the cavity.

Table 2.1 Different characteristics of outline form in cavity preparations between conventional GV Black and minimal intervention concepts (Mount and Hume, 2005; Roberson et al., 2006)

Characteristics of outline form in cavity preparation	Conventional concept	Minimal intervention concept
Occlusal portion	Extension for prevention with definite line and point angles	More conservative approaches such that 'extension for prevention' is not followed, rounded internal preparation
Proximal portion	Box type or inverted cone shape	Only a unilateral inverted cone shape is needed to preserve tooth structure
Isthmus	No greater than 1/3 intercuspal distance	No greater than 1/4 intercuspal distance

In DCP 3, students consolidate their knowledge and skills in simple restorative dentistry and are introduced to skills required for more complex restorative and endodontic procedures. The DCP 3 course also consists of preclinical laboratory exercises, class meetings, lectures, seminars, and clinical sessions. The students are required to demonstrate satisfactory knowledge and skills prior to providing treatment for patients. A satisfactory level of performance in the preclinical operative technique exercises is also one of the requirements that students must achieve before commencing patient care. By the time that Phase I of the current study had been conducted, students had been involved in exercises relating to simple restorative dentistry for three weeks (see Appendix 9). This included four laboratory sessions in which they were provided with radiographic images and photographs of virtual patients. Students were required to complete operative work on their Frasaco™ models according to the information provided about their patient. At the beginning of laboratory sessions, students were required to consider with their tutor and peers questions related to the patients, eg which burs would be needed for the cavity preparation, how to draw a cavity outline and what was the rationale for the design of the outline. Exercises included Class II amalgam preparations and cusp capped amalgam preparations. Therefore, learning outcomes measured in Phase I of the study were those reflecting what students had learnt in DCP 2. This did not include clinic experience with patient treatments.

In summary, the operative technique laboratory sessions in the DCP2 course provided a logical opportunity to investigate factors influencing psychomotor skill learning in dental students. This course was selected as it is the first course in the Adelaide dental program where concentrated psychomotor skill development occurs, apart from a wax carving exercise in first year. The exercises in the sessions provided a range of tasks that require basic psychomotor skills required in future clinical domains. There were some aspects of the laboratory sessions that differed between the third-year and the second-year cohorts, eg differences in the sequence of exercises in the DCP 2 laboratory sessions, different tutors and some differences in course materials, and this needs to be taken into account when interpreting the findings. Therefore, data from both cohorts were analysed separately.

2.3 Research materials and methods

In this section, detailed information about research materials and methods used in the study will be provided. This will be presented in the same order in which the various instruments were used in the study rather than in the order within the literature review in Chapter 1. Therefore, the subsequent sections include discussion of: 1) psychometric tests (MacQuarrie, 1953; Smith, 1982; Peters et al., 1995; O'Connor, 1998; Raven et al., 1998; Burns and Nettelbeck, 2005) 2) written exercises,

3) cavity preparation exercises, 4) a motivation survey (Ryan, 2001), 5) observational protocol (Chambers and Geissberger, 1997), 6) retrospective think-aloud interviews (Feil and Gatti, 1993; Nielsen et al., 2002), and 7) critical incident techniques (Dunn and Hamilton, 1986; Norman et al., 1992; Victoroff and Hogan, 2006). To ensure an appropriate instrument was selected, a range of sources of validity evidence was considered to ensure valid interpretation of data (Cook and Beckman, 2006). Sources of evidence relating to the validation of instruments used in the current study are presented in Table 2.2. Further information about the validity of the instruments used in the current study is given in Chapter 3.

Table 2.2 Sources of evidence for validating the instruments used in the study

Instrument	Intended inference from scores	Source of information to validate each evidence category				
		Content	Response process	Internal structure	Relation to other variables	Consequences
Psychometric tests (Standardised tests)	Level of measured ability	• Tests were selected based on: underlying components are similar to the cavity preparation exercise, several of these tests have been used in previous studies	• Recommended instructions were used • Answers were monitored for unexpected responses indicating students' understanding of the questions	• Intra-rater reliabilities were assessed • Tests were provided by the same staff member to all participants	• Scores from cohorts were checked with norms where applicable	• Not applicable
Written exercise	Level of knowledge about cavity preparation	• Derived from objectives of DCP2 course • Questions in the exercise related to motor learning parameters (DO, DP)	• Answers were monitored for unexpected responses indicating students' understanding of the questions • Questions were trialed with several 5th yr students and timed; questions were modified based on students' responses in the trial	• Intra-rater reliabilities were assessed	• Results were checked for matching with comments by tutors in the formative assessment tutor form (knowledge base) (not analysed in this study) • Results were checked for matching with scores obtained from final written exercises in which similar questions have been asked (not analysed in this study)	• Students demonstrated an understanding of their knowledge related to cavity preparation which can be identified in self assessment procedures (not analysed in this study)
Cavity preparation exercise	Competence in cavity preparation	• Derived from objectives of DCP2 course • Components in exercise consisted of basic cavity preparation tasks	• Criteria for grading were discussed among three raters (calibration procedures) • Interview data were used to identify if students used motor learning parameters • Cavities were monitored for unusual responses as an indication of students' understanding of the exercise	• Inter-rater and intra-rater reliabilities were assessed. • Assessment of performance of different groups of students/staff with different levels of experience	• Results were checked for matching with comments by tutors in formative assessment tutor form, especially relating to manual dexterity (not analysed in this study) • Results were checked for matching with summative assessment for lab& clinical activities (not analysed in this study)	• Students demonstrated an understanding of their skills related to cavity preparation which can be identified in self assessment procedures (not analysed in this study)

Note: DO - desired outcome, DP - desired performance, DCP 2 – Dental Clinical Practice 2 course

Table 2.2 Sources of evidence for validating the instruments used in the study (con't)

Instrument	Intended inference from scores	Source of information to validate each evidence category				
		Content	**Response process**	**Internal structure**	**Relation to other variables**	**Consequences**
Motivation survey (Standardised test)	Participants' subjective experience related to the cavity preparation exercise	• The survey was selected based on what has been used in previous studies	• Recommended instructions were used	• Factor analysis to identify distinct subscales of motivation and the results were completed	• Not applicable	• Not applicable
Observational protocol	Time spent	• The protocol was modified from the protocol used by Chambers and Geissberger (1997)	• Observation codes were discussed among three observers • The protocol was trialed with several 5th yr students	• Inter-rater reliabilities were assessed	• Not applicable	• Not applicable

2.3.1 Psychometric tests

To better understand which abilities were most associated with psychomotor skills in operative dentistry, all abilities that have been defined according to skill acquisition theory (Ackerman, 1988) were measured. To ensure the content validity of psychometric tests, suitable cognitive ability, perceptual speed ability and psychomotor ability tests (see example of the tests in Appendix 10) were drawn from standard psychometric tests (Table 2.3). Tests were chosen based on their theoretical basis and how closely they matched characteristics required in dentistry. Most of the tests had also been used in previous studies in dentistry (de Andres et al., 2004) or a related area, eg surgery (Keehner et al., 2006). To ensure that tests were representative of the ability of interest (Creswell, 2005), the final decision as to which tests would be used was made after discussion with Associate Professor Nicholas Burns, School of Psychology, The University of Adelaide. Recommended instructions were used to ensure the response process of the tests. In terms of the internal structure of the tests, intra-rater reliabilities were assessed and the tests were also provided by the same staff member to all participants.

Table 2.3 Details of psychometric tests used in the current study

Name	Measured ability	Description of the test	Score
Raven's Advanced Progressive Matrices (Raven et al., 1998)	Cognitive (abstract reasoning)	Participants must find the next item missing from a series of 12 pictures with unlimited time.	Total number of problems that participants can solve (total score=12)
Mental Rotation test (Peters et al., 1995)	Cognitive (spatial content)	This test consists of 24 items with one stimulus and four different figures rotated in various configurations. Participants are required to identify two from four figures that are the same as the stimulus. Correct answers are recorded when both answers are correct. Four minutes is allocated for each subset of 12 problems.	Total number of problems that participants can solve (total score=24)
Symbol Digit Modalities test (Smith, 1982)	Perceptual speed	Participants must write down the numbers, which are given as a key for each symbol, and try to match 100 symbols within 90 sec.	Total number of problems that participants can solve (total=110)
Inspection Time test (Burns and Nettelbeck, 2005)	Perceptual speed	This test involves visual backward pattern masking. Two high-contrast lines are presented side by side (one line is shorter than the other), followed by a pattern mask consisting of two longer lines that overlie the target stimulus. Participants must identify which target line is shorter (left or right).	Time spent to identify target line with high accuracy (msec)
MacQuarrie test: Tracing (MacQuarrie, 1953)	Psychomotor	Participants must draw a continuous line through 80 small gaps within vertical lines in 50 sec without touching vertical lines.	Number of gaps where vertical lines are not touched (total score=80)
MacQuarrie test: Tapping (MacQuarrie, 1953)	Psychomotor	Participants must make three dots in each 1-cm diameter circle (70) within 30 sec.	Number of completed circles (total score=70)

Name	Measured ability	Description of the test	Score
MacQuarrie test: Dotting (MacQuarrie, 1953)	Psychomotor	Participants must make one dot in each 5-mm diameter circle (100) without touching circumference within 30 sec.	Number of circles with dot where circumference is not touched (total score=100)
O'Connor Tweezer test (O'Connor, 1998)	Psychomotor	Participants must fill up 100 holes with pins using tweezers with unlimited time. The company's instruction determines the procedures to be used for administration processes.	Time spent in completing the task (mins)

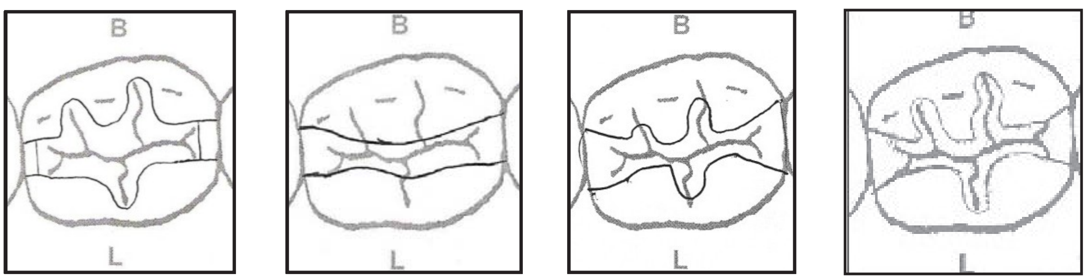
2.3.2 Written exercise

This exercise included questions about how to prepare a cavity that were derived from parameters from motor learning theory (Feil and Gatti, 1993; Schmidt and Lee, 2005) (Table 2.4). Specifically, the questions tested knowledge about appropriate cavity design, restorative materials, burs and the cavity outline. A scenario was provided to students in which a patient had undergone a clinical examination and a radiographic image showing the extent of caries was provided. Students were informed that an MOD cavity preparation for an amalgam restoration was needed on tooth 36 and they were then required to answer three questions (see details in Appendix 11).

Table 2.4 Questions in the written exercise and relevant parameters from motor learning theory

Question	Objective	Measured parameters
1	Discuss which specific burs are need for preparing the tooth	Knowledge of performance
2	Draw a cavity outline on a standardised diagram provided	Desired outcome
3	Discuss the rationale for the cavity design	Desired outcome

To address the content validity of this exercise, it was developed by a panel of clinical educators to assess clinical skill development. The response process of the exercise was assessed with a group of fifth-year students. The questions were modified based on students' responses to clarify the wording. An answer key was developed by the candidate in conjunction with the DCP 2 course coordinator. The de-identified written exercises were graded by the candidate in two separate sessions to determine intra-rater reliability. Firstly, all the responses for Question 1 were graded, followed by grading all the responses for Question 2, and then all the responses for Question 3 were graded. Question 1 was graded into three categories: Unsatisfactory (U), Satisfactory (S), and Good (G). These grades were assigned based on whether the types of burs that students used were appropriate, as well as the reasons for using those burs (see expected responses in Appendix 12). Question 2 was graded into four categories: Unsatisfactory (U), Unsatisfactory Redeemable (UR), Satisfactory (S), and Good (G) (Figure 2.3). The grading criteria were based on clinical acceptability (see criteria in Figure 2.4). Question 3 was graded into two categories: Unsatisfactory (U) and Satisfactory (S) based on the requirements for an MOD amalgam cavity preparation (see expected responses in Appendix 12).



Unsatisfactory | Unsatisfactory Redeemable | Satisfactory | Good

Figure 2.3 Examples of various participants' cavity outlines drawn on the standardised diagram that was provided (Question 2)

2.3.3 Cavity preparation exercise

As psychomotor skills are needed in more complex clinical tasks, cavity preparation exercises on plastic teeth were selected to assess students' preliminary capabilities in acquiring these skills and to ensure the content validity of these exercises. The students were required to prepare an MOD amalgam cavity based on information provided in a written scenario with burs provided (see Appendix 13). The current study required students to prepare the cavity according to the modified version of GV Black's cavity design (see section 2.2). As certain aspects of cavity design are needed to achieve satisfactory outcomes, this allows an assessment of psychomotor skills in cavity preparation exercises. The response process of the exercise was also addressed by having calibration procedures for assessors (see details in section 2.3.3)

To determine the internal structure of the cavity preparation exercise, fourth-year students (n=24) and staff members (n=19), who had at least 5 years clinical experience, were recruited to complete the MOD cavity preparation in 30 minutes. This aimed to investigate whether the exercise could differentiate between outcomes produced by practitioners and dental students The prepared teeth from these two groups and a subset of prepared teeth (n=27) randomly selected from the second-year cohort were graded by the candidate and a third-year dental student[1]. The assessors were blinded to participants' level of performance. A calibration process was conducted between the two assessors and the reliability of the grades obtained in the

[1] The validity study was part of a vacation research project conducted by a third-year BDS dental student co-supervised by the candidate.

exercises was determined by repeating the grading of all preparations within a two-week interval.

The models were collected at the completion of the exercise. The cavity preparations were photographed in situ. The teeth were then removed from the models and retained by the candidate. They had been provided to students as part of the research project. The models were returned to the students. Teeth were identified with a three or four digit code so that the assessors were unaware of students' identities.

As Phase II involved collecting cavity preparations from second-year students at the commencement of the DCP 2 course, a video was used to provide the necessary information for students to be able to complete the exercise. A video of the procedure of interest has been used in a previous study to provide instructions to novices for completing bone plating in surgery (Dubrowski et al., 2005). A 20-minute video was developed of the DCP 2 course coordinator completing an MOD cavity preparation for amalgam restoration on tooth 36. The preparation was completed following the same procedures that the students would use. The video included instructions about cavity preparation procedures and the manipulation of instruments. These instructions were given by the DCP 2 coordinator when carrying out the exercise. The video was shown to students on one occasion and then they were required to complete the exercise within 30 minutes.

In addition, photographs of the cavity preparations produced by students during four key DCP 2 laboratory sessions were also collected. The first two sessions, ie weeks 5 and 6, session 1 of the DCP 2 laboratory schedule (see details in Appendix 6), involved occlusal cavity preparation exercises for composite resin and for amalgam on the lower molar teeth. Subsequently, two sessions in weeks 9 and 10, session 1 of the laboratory schedule (see details in Appendix 6), involved mesio-occlusal (MO) and mesio-occluso-distal (MOD) cavity preparation exercises on lower molar teeth (see example of the cavity preparations in Appendix 14). As these exercises formed part of the normal laboratory exercises, the preparations were subsequently restored by students in the next session and, therefore, only photographs were collected.

2.3.3.1 Cavity preparation grades and calibration

Criteria for grading students' performance on the cavity preparation exercises and the photographs of the cavity preparations were based on clinical acceptability (Figure 2.4). That is, the cavity was judged according to whether it could be restored effectively and would function appropriately in the oral cavity. The criteria were developed and discussed by three assessors (the candidate and two experienced academic staff members involved in teaching the DCP 2 course) to ensure that there was a common understanding of the criteria and standards. To simulate the situation occurring in a clinical setting, the examiners graded the cavity preparations without using any measuring instrument. For the photographs of the cavity preparations, a digital SLR camera stabilised with a camera stand was used to ensure standardisation of the orientation the camera. The photographs were printed in gray-scale color for grading.

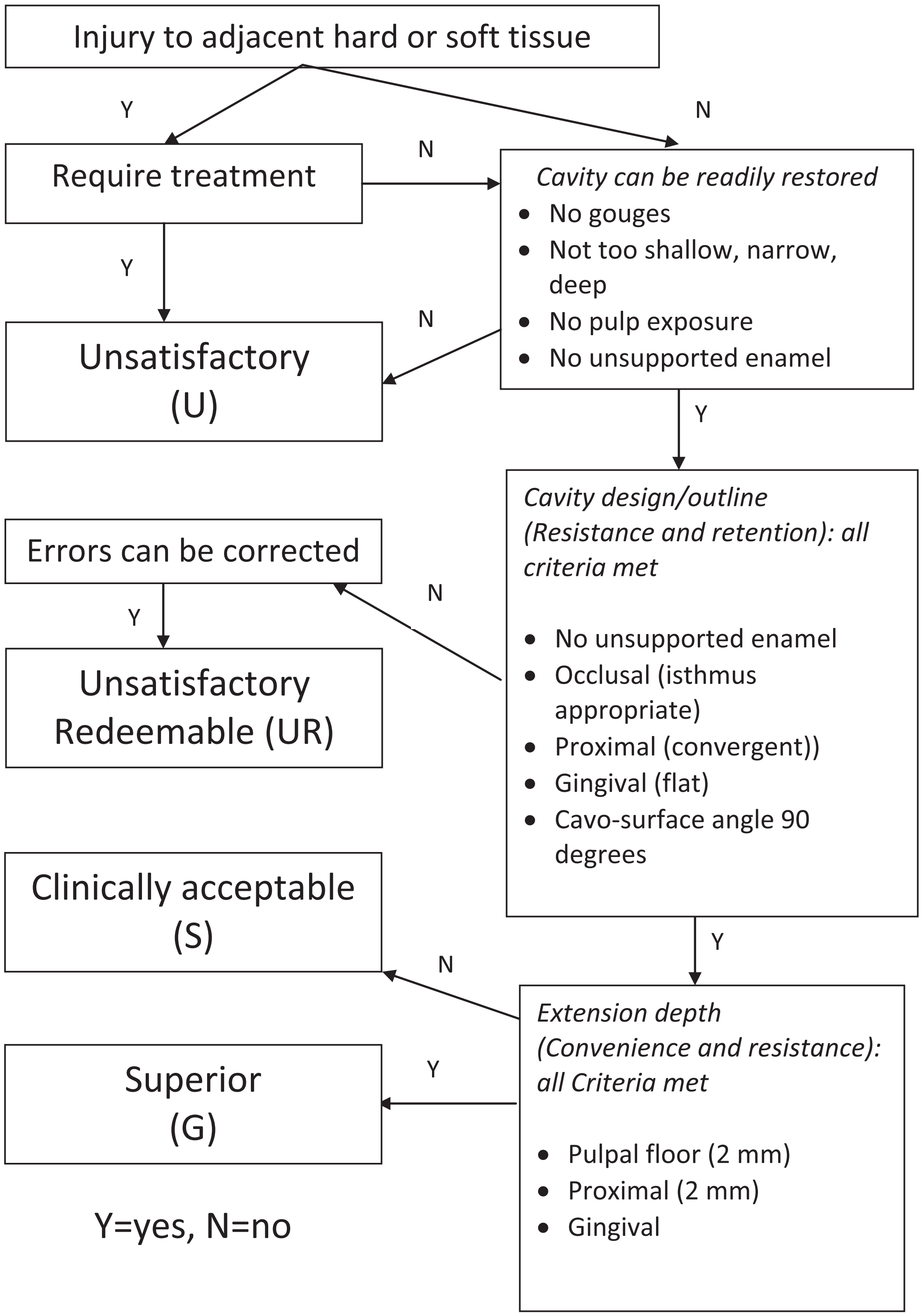
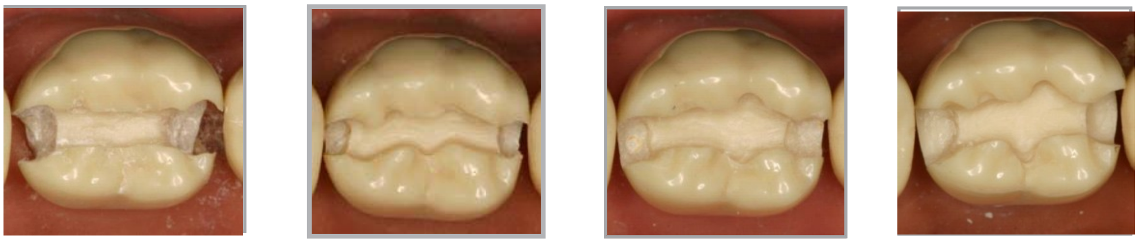


Figure 2.4 Criteria for grading the cavity preparation exercise (36 MOD-amalgam)

The prepared teeth and the photographs were graded into four categories: Unsatisfactory (U); Unsatisfactory redeemable (UR), Satisfactory (S), and Good (G) (see examples in Figure 2.5) based on criteria noted in Figure 2.4.



Unsatisfactory | Unsatisfactory Redeemable | Satisfactory | Good

Figure 2.5 Examples of various participants' MOD amalgam cavity preparations on tooth 36

For the third-year cohort, 12 teeth (16%) were selected randomly from the total of 74 teeth and graded independently by each of the three assessors. After grading, the assessors discussed the grades they had assigned and identified any differences before reaching consensus on the application of the criteria (Gansky et al., 2004). The assessors then individually graded another 24 teeth (32%) and the percentage of agreement in grades was calculated to assess inter-examiner reliability. The candidate then graded the remaining teeth (52%). In addition, data for the cavity preparations (tooth 36) produced at the end of semester 1 and 2 of the second year were available (these had been collected as part of another research project). These teeth were also graded by the two academic staff and differences were discussed before reaching consensus on the final grades.

For the second-year cohort, 104 teeth collected at the end semester 1 and 2 were graded by the three examiners over two separate sessions. In the first session, 26 teeth (25%) were randomly selected and used for calibration procedures. The procedures were similar to those for the third-year cohort, with all assessors being familiar with the criteria. Assessors independently graded a further 26 teeth (25%) and the percentage agreement in grades was calculated to assess inter-examiner reliability. In the second session, the remaining teeth (n=52) were graded independently and then reviewed prior to assigning final grades.

Two hundred and eight photographs were graded by the three assessors over two separate sessions. In the first session, similar procedures were used for calibration (12.5% of the teeth) and grading (12.5% of the teeth) to those used for the cavity preparation exercise. In the second session, 75% of the teeth were assigned final grades followed by discussion amongst all three assessors. To assess intra-assessor grading reliability, all teeth from the three datasets were graded again at least one week later by the candidate.

2.3.4 Motivation survey

As noted previously, this study focused on selected parameters of motivation as part of a theoretical framework. Questions in the survey were selected from the Intrinsic Motivation Inventory test (IMI) (Ryan, 2001) to ensure the content validity of the survey. The survey was used to indicate students' levels of intrinsic motivation. This survey is designed to assess learners' experience related to a particular activity and this was considered appropriate for the current study. This survey consists of three subscales related to the participant's effort, pressure and perceived value of a task. A minimum of four statements per subscale were included (Ryan, 2001) as a result, the survey comprised 14 statements with a seven-item rating scale ranging from 1 (not at all true) to 7 (very true). Statements were selected for each subscale and these were approximately equal in the number. The statements were selected based on instructions given (Ryan, 2001), eg numbers of similar meaning and negatively worded statements were included in each subscale (see example in Appendix 15). Ryan (2001) recommended that there should be multiple items in each subscale to obtain better external validity and that a reversed statement be included in each subscale with more than four statements. The statements were then modified slightly to fit the cavity preparation exercise and randomly ordered. The score for each subscale was represented by the average score of the related group of statements (McAuley et al., 1989). In terms of the internal structure of the survey, factor analyses of subscales were conducted to check whether statements fitted the same factor structure as the original survey (see details in Chapter 3)

2.3.5 Observational protocol

Motor performance during the cavity preparation exercises was video-recorded and/or observed following an previously developed observational protocol (Chambers and Geissberger, 1997) to ensure the content validity of the protocol. This observation was completed by the candidate (Phase II) and/or two trained observers (Phase I). To determine the response process of the protocol, it was modified and trialed with a group of students in a pilot study (see details in section 2.3.5.1). The internal structure of the survey was determined by assessing inter-rater reliabilities among assessors. Times spent on various operations during cavity preparation were recorded. The main operations were noted every 10 seconds (Chambers and Geissberger, 1997). Operations were coded into five different activities as shown in Table 2.5. The context of data collection using this technique is described in subsequent sections.

Table 2.5 Definitions of codes used in the observational protocol

Code	Definition
Cutting (C)	Time spent continuously cutting the teeth with a rotating bur
Observation (O)	Time spent without cutting but using a triplex syringe to clean the cavity, or a mirror to check the preparation, or obtaining and returning an instrument to the tray
Change of instrumentation (X)	Time spent changing instruments, for example, high speed/slow speed handpiece or a hand instrument
Checking the preparation (I)	Time spent checking the preparation with a periodontal probe
Stopping (S)	Time spent without cutting but without putting the handpiece down, examining the preparation, or looking around.

Note: The codes were modified from the protocol used by Chambers and Geissberger (1997)

2.3.5.1 Pilot study

A pilot study of the observation and videoing of students was completed with volunteers from the 5th year (2006) of the Adelaide BDS program. The aims were to indicate the position of observers and locate the position of the video-recorder where performance of students could be observed and recorded clearly. Subsequently, the video was used in training sessions for observers and interviewers (see detailed information in section 2.3.6.1).

2.3.5.2 Observational protocol for Phase I

Three observers including the candidate were involved in recording observational protocols. The observers recorded students' performance from a position where they could clearly see which instrument was being used throughout the exercise. One observer recorded one student at a time while a video-recorder was used to film the procedure. The video-recorder was periodically adjusted to provide an image of the overall operation area as well as close-up views of the cavity preparation.

2.3.5.3 Observational protocol for Phase II

Because the candidate performed all observations, groups of 3-4 students were observed at a time during the actual laboratory sessions. The candidate was positioned where the performance of the students could be observed clearly, including which instruments they were using throughout the cavity preparation exercises. When the candidate completed recording for one group of students, the candidate started to record another group of students, with observations for 7-8 students being recorded in each laboratory session. As there were several cavity preparation exercises in each laboratory session, students were asked to record the total time they spent for each exercise. The recorded time was then matched with the observational records.

To ensure internal structure of observation codes recorded by the three observers in Phase I, two training sessions were conducted. In the first session, the identification of codes and observational positions were discussed using videos obtained from the pilot study. After viewing a 10-minute segment of the video, the three trainees independently completed a protocol, followed by discussion of any discrepancies using a master protocol that the candidate had created previously. The trainees then viewed another two 10-minute segments of different videos and the percentage of agreement with the master protocol was found to be 90%. A further 10-minute segment of the video was shown one week later and the percentage of agreement was calculated at 80% agreement. Differences in codes identified by the trainees were discussed before reaching consensus on the application of the final protocol (see Appendix 16). To ensure accuracy of the observation codes that observers assigned during the cavity preparation exercise, the candidate completed another observational record for each student using their video-record prior to conducting data analysis.

2.3.6 Retrospective think-aloud interviews with third-year cohort (Phase I)

Two approaches of thinking-aloud have been used to gain access to cognitive processing of students during motor skill learning. These involve either a concurrent (Blackwell et al., 1985; Nielsen et al., 2002; Wilhelm and Beishuizen, 2004; Hall, 2005; Rikard and Langley, 1995) or a retrospective method (Guan et al., 2006). It has been shown that the concurrent method can draw out thinking processes from learners during a task without affecting the quality of the task (Blackwell et al., 1985; Nielsen et al., 2002; Wilhelm and Beishuizen, 2004; Hall, 2005; Rikard and Langley, 1995) but this method may affect the speed of performance (Wilhelm and Beishuizen, 2004). The suggestion that the retrospective method is compromised by the limitation of short-term memory is not supported by the literature, with no differences in results from these different methods being reported (Guan et al., 2006). In addition, this impact can be minimised by using a videotape as a stimulus to facilitate recall of information from short term memory after completing a task (Davison et al., 1997; Guan et al., 2006). For this reason, the retrospective method provides an alternative for situations in which the concurrent thinking-aloud method is inappropriate, such as the current study in which the exercises were completed as part of normal class activity.

Data recorded by the observers, as well as the videotapes, were used for reviewing procedures with students in a subsequent 30-45 minute-interview session. Structured interviews were conducted immediately after students had completed the written and cavity preparation exercises. The three interviewers involved in interview sessions used standardised questions derived from training sessions (see section 2.3.6.1). These interviews aimed to collect data on the students’ thinking processes and motor learning parameters that they used during the cavity preparation exercise. Structured questions were used to obtain verbal self-reports of thinking processes and motor learning parameters derived from motor learning theory that occurred at specific times during the exercise, using segments of the videotape as prompts for discussion. These questions were modified from the existing literature (Feil and Gatti, 1993) and were trialed with a group of students as noted previously in section 2.3.5.1. The aims of the pilot were to find out how students interpreted the questions and to develop materials for training the interviewers. Following the pilot, the wording of some questions was modified to enable students to better understand them (see Appendix 17). For example, some students in the pilot group were unclear on the meaning of the question; ‘How much do you focus on evaluating the relationship between the bur and tooth?’. This question was then modified to ‘How much emphasis do you place on evaluating the relationship between the bur and tooth?’ as this question aimed to identify the weight of their attention during the cavity preparation exercise. The comments of interview participants were recorded and transcribed by a professional transcriber.

2.3.6.1 Training interviewers

To ensure ease of use of the video-recorder during interviews and to standardise the interview processes among the three interviewers, two training sessions were arranged. In the first session, trainees were provided with examples of interview questions and were shown when and how to ask a particular question in relation to performance in the video. Role plays, performed by the candidate and a researcher experienced with conducting interviews, were used to simulate real situations in an interview session. In the second session, principles and practicalities of the interviews were discussed, eg how to ask questions to explore further information of interest.

2.3.7 Critical incident technique and subsequent interviews (Phase II)

2.3.7.1 Written critical incident report

To explore a broad range of learning experiences during the laboratory sessions, a written critical incident report was used to sample larger groups of students in the second-year cohort than is possible with individual interviews. This report included questions modified from key questions used in previous studies (Victoroff and Hogan, 2006). The questions explored learning activities that students perceived to be effective or ineffective in supporting their learning in the laboratory sessions. The questions also addressed learning parameters derived from motor learning theory. This aspect of the study was conducted at the conclusion of selected laboratory sessions in Phase II of the study. These sessions were chosen according to the complexity of the exercises that students had to complete in relation to an MOD cavity preparation on tooth 36 (see details in section 2.4.2).

To check that students understood the format of the critical incident report, a report was completed initially by second-year volunteers who formed part of the study sample. This report was collected after a laboratory session that did not generate any of the planned data set. The report was then modified in terms of its format and the content of questions after discussion with the students. For instance, the amount of information provided in the instruction section was reduced and the format of the questions was adjusted to form a list of short statements (see details in Appendix 18).

2.3.7.2 Interview

To gather further information about issues identified by students in their written critical incident reports, short interviews were completed after each time a report had been collected. Students involved in the interview component were chosen based on issues in their critical incident reports that specifically linked to key learning parameters in motor learning theory. The interview component was conducted to explore students' perceptions of effective and ineffective learning experience during laboratory sessions. Initially 8-12 students were selected followed by sampling of further students until no new ideas arose from the interviews (Rice and Ezzy, 1999).The interviews consisted of several open-ended questions that explored learning experiences noted in the written critical incident report. In addition, questions that had been used in the retrospective think-aloud component were also asked to gain further information about students use of motor learning parameters during the cavity preparation exercise completed in the session described in the report.

2.4 Description of the sequence and timing of data collection

In this section, the sequence and timing of data collection of the study will be described.

2.4.1 Phase I

At the commencement of the DCP 3 course in 2007, cognitive, perceptual speed and psychomotor abilities were assessed using the standard psychometric tests described in 2.3.1. These tests were completed by all participants before data relating to motor performance and motor learning were collected. Exercises relating to third-year students' motor performance and motor learning were conducted after three weeks of the third-year BDS program during a regular laboratory class. The data were collected using a written exercise and a cavity preparation exercise. As noted previously, the written exercise addressed theoretical knowledge and motor learning theory parameters related to the cavity preparation exercise. The cavity preparation exercise was completed within a 30-minute period. During the completion of these exercises, no tutor feedback was given. In addition, students' motivation during completion of the cavity preparation exercise was assessed using the motivation survey (see details in section 2.3.4) (Ryan, 2001). The survey was used immediately after students had completed the cavity preparation.

During the cavity preparation exercise, the actions of the two sub-groups of students, ie students selected based on higher and lower levels performance in second year, were recorded by video and using a written observational protocol completed by trained observers (details in 2.3.5 and 2.3.6). The observers/interviewers were unaware of the students' performance levels during the observation and in subsequent interview sessions to minimise bias. The video and observational records were used in individual retrospective think-aloud interviews (Feil and Gatti, 1993; Guan et al., 2006) with trained observers/interviewers. To accommodate the constraints related to facilities, equipment, personnel and timetabling, three students were videoed, observed, and then interviewed within a two-hour period. On consecutive days, two laboratory sessions were run, each for two hours duration, ensuring that all 12 selected students completed the exercises and were interviewed.

2.4.2 Phase II

A cohort study involving second-year dental students was designed to collect data on the development of learning outcomes and performance. In addition, this study also investigated learning experiences related to skills training in the laboratory sessions. Data for the learning outcomes were collected using the same activities as in Phase I, namely a written exercise and a cavity preparation exercise. In order to determine the contribution of innate abilities and motivational determinants to cavity preparation outcomes, these determinants were assessed using standard psychometric tests and the motivation survey. Data related to the performance of students were collected by observation records to monitor the progression of performance. Data for the learning experiences were also collected by exploring the characteristics of what students perceived as effective and ineffective learning experiences in laboratory sessions, using a written critical incident approach (see section 2.3.7) and follow-up interview.

Data for three abilities were assessed at the beginning of the course. Data on outcomes were collected at three different time periods, ie prior to learning in the course (week 2 – session 1: see Appendix 6), and at the end of semesters 1 and 2 (week 11 – session 1). All students were required to complete the written exercise followed by the cavity preparation exercise (an MOD cavity preparation for amalgam on tooth 36) and the motivation survey at the end of each semester as part of their usual class-based activities. The written exercises were not included in the pre-learning phase as this was completed prior to any instruction about the course. During the pre-learning phase, students viewed the video of an expert performing the cavity preparation exercise with instructions provided about the instrumentation needed (see section 2.3.3). Cutting burs noted in the instructions of the video were provided to students (see Appendix 13). This was followed by the completion of the cavity preparation within a 30-minute period. These exercises were completed at three time periods without tutor feedback. However, the cavity preparations that students produced during four key laboratory sessions (see section 2.3.3) were completed under supervision of tutors where feedback was provided as requested.

Data related to learning performance were obtained from selected groups of consenting students as part of their usual participation in class, using observational records (n=10-11 from each end of the performance range). The selection criteria for students were based on performance in a manual dexterity exercise and a specific cavity preparation exercise as described in section 2.1.7. Data collection was conducted with the same group of students over semester 1, particularly for exercises related to the specific 36 MOD cavity preparation. The observational component involved approximately 30 minutes per group of students in four consecutive laboratory sessions as shown in Table 2.6. The time spent on various activities during cavity preparation was recorded by the candidate using a similar protocol as that in Phase I (see section 2.3.5).

Table 2.6 Details of activities in the laboratory sessions in semester 1 of the DCP 2 course selected for an observational component involving the second-year cohort

Week*	Topic	Activities
5	Occlusal (composite resin) GV Black	46,47,48
6	Occlusal (amalgam) GV Black	36,37,38
	Mid-Semester break (2 weeks)	
9	Slot with Occlusal (composite resin) GV Black	46MO, 47MOD
10	Slot with Occlusal (amalgam) GV Black	36MO, 37MOD

*week number in the 12-week course (does not include the 2-week break), data were collected in the first of two laboratory sessions in each week (see Appendix 6)

Data on students' learning experiences were also obtained using a written critical incident report form from all consenting students at the end of four key laboratory sessions (two per semester – see Table 2.7). These sessions were chosen based on the complexity of exercises and cavity preparation skills that were needed for the 36 MOD cavity preparation exercise. In week 6, semester 1, students had completed several cavity preparation exercises involving an occlusal surface. As it was the first few weeks of the course, it was expected students might have issues related to their learning experiences. In week 10, semester 1, students accomplished more complicated exercises, ie cavity preparations involving both the occlusal and proximal surfaces. These exercises required new procedural knowledge to complete the tasks. In week 8, semester 2, students had completed several exercises before a two-week semester break. These exercises were allocated to students based on a patient scenario. In week 11, students completed the 36MOD cavity preparation exercise and this was followed by self-directed activities, eg 46MOD cavity preparation, after discussion with their tutor. They had also completed 46MOD, 16MOD cavity preparations for amalgam in weeks 9 and 10. These exercises were completed in plastic anatomical teeth in which the internal structure was composed of different materials to differentiate between enamel and dentine layers.

Table 2.7 Details of activities in the laboratory sessions in semester 1 and 2 of the DCP 2 course selected for the critical incident report involving the second-year cohort

Week	Topic	Activities
5*	Occlusal (composite resin) GV Black	46,47,48
	Mid-semester break (2 weeks)	
10*	Slot with Occlusal (amalgam) GV Black	36MO, 37MOD
	Semester break (4 weeks)	
8**	Slot with Occlusal (composite resin) in anatomical teeth GV Black	46MOD
11**	Cavity preparation exercise Self-directed activities	36MOD

*semester 1, **semester 2, data were collected in the first of two laboratory sessions in each week (see Appendix 6)

To gather detailed information about issues arising from the written critical incidents, interviews were arranged and conducted by the candidate with a selection of students (see section 2.3.7). A 20-minute interview with each student was conducted within one week after the completion of the written critical incidents. Each interview was audio-recorded and participants were assured that only the candidate had access to their interview tapes.

2.5 Data management and collection

To maintain student confidentiality, all data analyses were completed on data that had been de-identified, coded and randomly sequenced. Records of participant lists and codes were not accessible to any academic staff member who was involved in teaching or assessment of students. The observation and interview tapes were transcribed confidentially by a professional transcriber who was external to the

University and did not know the students' identities. Each student was assigned with a code and only the candidate had access to the name and code of each student. Three sets of codes were randomly used for data sets to eliminate bias during data analysis. For each time point, a different set of random codes was used to eliminate bias that might occur during data entry.

2.6 Data analyses

Power analysis indicated that a sample size of 80 was needed to determine the relationship between variables of interest. The analysis involved two main data sets as follows: a) quantitative data from the individual ability tests, written exercise, cavity preparation performance, motivation survey and observation data, and b) qualitative data related to retrospective think-aloud interviews, written critical incident reports and related interview components. Table 2.8 shows a summary of the data sets collected from students in both cohorts. Details of analyses are described in subsequent sections.

Table 2.8 Summary of datasets collected in the current study

Measurement	Variables	Phase I: Third-year cohort 2007*	Phase II: Second-year cohort 2008**
Psychometric tests	• Abilities	√	√
Written exercises	• Theoretical knowledge • Motor learning parameters	√ (1 session)	√ (2 sessions)
Cavity preparation exercises	• Motor performance (outcomes)	√ (1 session)	√ (3 sessions)
Motivation survey	• Motivation	√ (1 session)	√ (2 sessions)
Observational protocol	• Motor performance (processes)	√ (1 session)	√ (4 sessions)
Retrospective think-aloud & interviews	• Motor learning parameters	√ (1 session)	-
Written critical incident report and interviews	• Learning experiences • Motor learning parameters	-	√ (4 sessions)

Note: *In Phase I, psychometric tests were used to assess three abilities (section 2.3.1) at the commencement of the DCP 3 course. Written exercises were used to assess theoretical knowledge about an MOD cavity preparation for amalgam (section 2.3.2). Students then completed a cavity preparation within 30 minutes (section 2.3.3), followed immediately by a motivation survey (section 2.3.4). During preparation of the cavity, time spent in each action during the task by two sub-groups of students was recorded (section 2.3.5). They were also videoed to enable clarification of thinking processes of students in subsequent interview sessions (section 2.3.6).

**Similar datasets were also collected in Phase II of the study. Three abilities were assessed at the beginning of the DCP 2 course. Written exercises were used to assess theoretical knowledge at the end of semester 1 and 2. Students completed a cavity preparation at the pre-learning stage and end of semester 1 and 2. The motivation survey was conducted immediately after the completion of the cavity preparation exercise, at the end of semester 1 and 2. Selected groups of students were observed during the completion of exercises in class in four laboratory sessions (see Chapter 2, section 2.3). Instead of using think-aloud interviews, critical incident reports (section 2.3.7) were used to identify students' perceptions of the practice environment in four laboratory sessions. These were followed by short interviews with a subset of students which also addressed motor learning parameters.

2.6.1 Quantitative Data

Descriptive statistics were used to summarise quantitative data from the psychometric tests, written exercises, cavity preparation exercises, motivation surveys and observational records. Detailed information is provided in subsequent sections. To address the first research question, regression analyses were used to examine relationships between these different data sets. Because the dependent outcomes in this study comprised grades obtained for cavity preparation, ordinal regression analyses (Kleinbaum and Klien, 2002) were used to determine the associations between scores on the psychometric tests and the motivation survey. To determine the effect of time on the relationship between scores on the psychometric tests and the grades obtained for cavity preparation, Generalised Estimated Equation models were generated (GEE) (Kleinbaum and Klien, 2002). Demographic characteristics such as age, gender and handedness were considered as covariates and interaction terms in the regression analyses. Statistical significance was set at $p<0.05$.

2.6.1.1 Psychometric tests

Data from the Raven's Advanced Progressive Matrices (Raven et al., 1998), Mental Rotation test (Peters et al., 1995), Symbol Digit Modalities test (Smith, 1982), Inspection Time test (Burns and Nettelbeck, 2005), MacQuarrie tests (MacQuarrie, 1953), and O' Connor Tweezer test (O'Connor, 1998) were summarised in terms of means and standard deviations or medians (for data that were not normally distributed) to provide data on students' individual abilities. T-tests were used to compare mean values and Mann-Whitney U tests were used to compare median values for scores obtained in the tests; a) between the study sample and reference groups, b) between sexes in each cohort, and c) between the two cohorts.

2.6.1.2 Written exercise, motor performance and motivation survey

Data from the written exercises and cavity preparation exercises were summarised in terms of the percentage of students falling within each level of performance. Chi-square tests were used to identify associations between grades for sketches of the cavity outline (see section 2.3.2) with grades obtained for the cavity preparation exercise. Rating scores from the motivation survey were summarised to indicate students' motivation in completing the cavity preparation exercise. Negatively worded statements were rescaled prior to data analysis by subtracting the corresponding score of the statement response from eight (scale 1-7, see Appendix 15), and using the resulting number as the statement score. T-tests were used to compare differences in mean values of motivation scores between both cohorts. Factor analyses were conducted to check whether statements included in the motivation survey fitted the same factor structure as the original survey.

2.6.1.3 Observational records

Time spent on different activities was averaged for each student in the sub-groups and then compared using the Mann-Whitney U test.

2.6.2 Qualitative Data

2.6.2.1 Interview

An inductive thematic approach was used (Rice and Ezzy, 1999), with content for analytical coding being drawn from the learning parameters derived from motor learning theory (Feil, 1989). The analysis resulted in a synthesis of the students' accounts of their thinking and experience in completing a cavity preparation exercise in third year and accounts of their learning experiences of practising cavity preparation exercises in the DCP 2 course.

2.6.3 Coding of qualitative data

2.6.3.1 Think-aloud interviews

Interview transcripts were read initially to obtain an overall impression of the information contained in them. The information was then grouped with respect to motor learning parameters (Feil, 1989) as follows: 1) identification of the desired outcome (DO); 2) identification of the desired performance (DP); 3) use of feedback from knowledge of results (KR); and 4) use of feedback from knowledge of performance (KP) (see details in Chapter 1, section 1.4.3). Each transcript was then summarised to identify individual characteristics and also to identify similar patterns of characteristics among the 12 participants. Based on explicit evidence from the literature that is outlined in Chapter 7, the coded data representing the characteristics of the students were placed into two groups. The masking of students' identities regarding which sub-group they came from was then removed to enable comparisons of the learning parameters used between the two sub-groups of participants.

2.6.3.2 Critical incident reports and interviews

Data obtained from the written critical incident reports and the interview transcripts were read to identify codes and themes and to explain learning experiences during the DCP 2 course. Data were grouped based on responses to questions in the reports (see section 2.3.7.1).

In summary, this chapter has outlined the research design adopted in this study with respect to the relevant theoretical frameworks, ie skill acquisition theory (Ackerman, 1988) and motor learning theory (Schmidt and Lee, 2005). Factors that have been identified according to these theories were investigated using a range of instruments. Each instrument was selected according to its validity and detailed information about the validity of the instruments will be given in the next chapter.

Chapter 3 - Validity of instruments

3.1 Introduction on validity of instruments

Validity of instruments refers to the meaning or interpretation drawn from test scores (Messick, 1995). Validity has been traditionally reported in different forms, eg content, criterion-referenced and construct validity (Creswell, 2005). Given that distinctions between these terms are essentially arbitrary, all validity has been conceptualised as construct validity (Cook and Beckman, 2006). Construct validity is required in educational research to ensure meaningful and trustworthy interpretation of assessment results (Downing, 2003; Beckman and Cook, 2007). Beckman et al (2005) suggested that validity is more focused on providing evidence to support meaningful interpretation rather than focusing on the property of the assessment tool itself. Five sources of validity evidence have been described in the context of medical education (Beckman and Cook, 2007) (see Table 1.1, Chapter 1). Based on these definitions, the types of information required to provide evidence about different forms of validity have been noted in Table 2.2, Chapter 2. This chapter summarises the construct validity of instruments used in the current study, ie a) psychometric tests, b) written exercises, c) cavity preparation exercises, d) the motivation survey and e) the observational protocol. Several sources of evidence were selected to support (Downing, 2003) interpretation of outcomes obtained using the instruments. The choice of evidence was based on feasibility in accessing the sources. Detailed information about the sources of evidence for each instrument is provided in the subsequent sections.

3.1.1 Psychometric tests

Three categories of evidence were analysed to provide support for the construct validity of the psychometric tests, specifically: content, response process and internal structure. Evidence supporting content of the instrument and response process were addressed by the selection of instrument that have been used in similar previous studies and administration procedures of the tests, ie following developers' recommendations (see Chapter 2, section 2.3.1). Furthermore, answers were monitored for unexpected responses indicating students' lack of understanding of the questions. In relation to the internal structure of the tests, intra-rater reliability of scores was found to be 100% for all tests except the Tracing and Dotting tests which was found to be 80%.

3.1.2 Written exercise

As for the psychometric tests, three categories of evidence were used to support the construct validity of the written exercise in this study, ie content, response process and internal structure. Content and response process were addressed previously in Chapter 2, section 2.3.2. In summary, questions were developed based on motor learning parameters from desired outcome (DO) and desired performance (DP) and then trialed with fifth-year students. The finding that there were no unexpected answers from the exercise provided further evidence to support the validity of the instruments in terms of response process, indicating that the students were clear about the questions in the exercise. The kappa statistics for intra-rater reliability for scores of the different questions in the exercise were 0.8 – 0.83 and 0.63 – 0.64 for the third-year and second-year cohorts respectively. These indicated ‘almost perfect agreement’ and ‘substantial agreement’ respectively (Cohen, 1960).

3.1.3 Cavity preparation exercise

The content of the cavity preparation exercise was derived from one of the objectives of the DCP 2 course. It consisted of several basic components of cavity preparation as discussed in Chapter 2, section 2.3.3. Two aspects of the exercise can be considered in relation to response process; a) application of the criteria used for grading and b) the cavity preparations. The first aspect was ensured by having three examiners discuss the criteria and reach consensus for grading discussions (see section 2.3.3). The second aspect was determined by reviewing data obtained from the interviews to confirm whether students had used motor learning parameters during the exercise (see detailed analysis in Chapter 5, section 5.3). As this exercise required theoretical knowledge related to dental anatomy and cavity design, as well as procedural knowledge, it was expected that verbal reports by students would indicate their understanding of the exercise. The results showed that they understood what was required.

Internal structure was assessed by intra-rater and inter-rater reliability and by performance of groups with varying levels of clinical experience. The kappa statistics for the cavity preparation exercise and the assessment of photographs for both cohorts are shown in Table 3.1. As the level of agreement for inter-rater reliability showed low agreement (kappa = 0.20), final grades used for analysis were assigned by consensus of the three examiners.

Table 3.1 Statistics for intra-rater and inter-rater reliability of grades obtained for cavity preparation exercises

Internal structure: Reliability	Kappa statistics	
	Third-year	Second-year
Intra-rater (cavity preparation)	0.74	0.35
Intra-rater (photos)	N/A	0.18-0.64
Inter-rater (cavity preparation)	0.20-0.56	0.41-0.47
Inter-rater (photos)	N/A	0.38-0.54

Note: N/A – not applicable

As predicted, there was a difference in grades obtained for the MOD cavity preparation completed by different groups of students and by staff members (see Chapter 2, section 2.3.3). A calibration process similar to that used in Phase I and II of the study was conducted and the following estimates of reliability were obtained as follows: a) inter-rater reliability: kappa statistic = 0.61 (substantial agreement) and b) intra-rater reliability: kappa statistic = 0.91 (perfect agreement). The results showed that staff members obtained higher grades in the exercise than fourth-year and second-year students respectively ($p<0.05$) (χ^2= 15.75, df=4) (Figure 3.1). Therefore, the cavity preparation exercise would appear to be an appropriate method to differentiate between individuals with different levels of clinical experience.

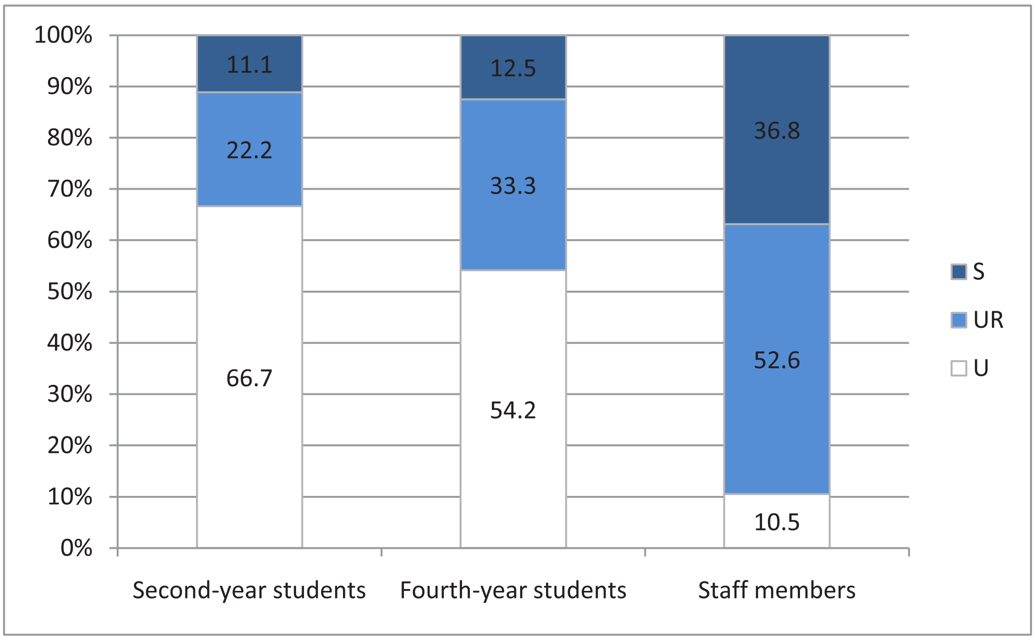


Figure 3.1 Summary of grades obtained for the cavity preparation exercise by different groups

Note: Grades: U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory

3.1.4 Motivation survey

Evidence supporting content of the instrument and response process were addressed by the selection of instruments that have been used in similar previous studies and administration procedures of the tests that followed developers' recommendations (see Chapter 2, section 2.3.4). To determine the internal structure of the motivation survey, factor analysis was conducted. Although this motivation survey has been shown previously to have internal reliability using factor analysis (McAuley et al., 1989), it is essential to perform another factor analysis when different statements have been used in a new context (Cook and Beckman, 2006).

As noted previously (see Chapter 2, section 2.3.4), three subscales were selected for the motivation survey (Ryan, 2001), ie perceived value of a task, pressure, and effort (Table 3.2). The perceived value subscale included statements 1, 4, 9, 11, 13, the pressure subscale included statements 2r, 6, 8, 12r (r=negatively worded), and the effort-subscale included statements 3, 5r, 7, 10, 14r. It was assumed that the responses of students to the statements from the same subscale would tend to load on the same component. In the current study, statements were grouped into a component (refer to 'component' in Table 3.3), if a component loading was 0.5 or more. The results showed that the numbers of extracted components differed over time. In the third-year cohort, three components were extracted, ie statements 1, 4, 7, 11, 13 loaded on component 1, statements 3, 5r, 8, 10, 14r loaded on component 2 and statements 2r, 6, 9, 12r loaded on component 3. It is clear that some statements loaded on different components from the original survey (Table 3.2). In cohort 2, four and three components emerged from the surveys conducted in semester 1 and 2 respectively. Again, some statements loaded on different components compared with the original survey. Nine questions were consistently grouped in the previously reported subscale, ie q1, 4, 11, and 13 for value/usefulness subscale; q3, 5r, and 10 for effort/importance subscale; and q6 and 12 for pressure/tension subscale. This indicates that, in this sample, those statements loading on different components may assess different dimensions of constructs compared with the original subscale.

Table 3.2 Statements in the three subscales derived from the original motivation survey

Subscale	Statements
Value/Usefulness	1. I believe this activity could be of some value to me.
	4. I believe doing this activity could be beneficial to me.
	9. I would be willing to do this activity again because it has some value to me.
	11. I think this is an important activity.
	13. I think this activity is important to do because it can help me developing skills for preparing a cavity.
Pressure/Tension	2r. I didn't feel nervous at all while doing this activity.
	6. I felt pressured while doing this activity.
	8. I was anxious while working on this task
	12r. I was very relaxed while doing this activity.
Effort/Importance	3. I put a lot of effort into this activity.
	5r. I didn't try very hard to do well at this activity.
	7. It was important to me to do well at this task.
	10. I tried very hard on this activity.
	14r. I didn't put much energy into this activity.

Note: The statements were selected from the original motivation survey (Ryan, 2001),
r – negatively worded statements

Table 3.3 Factor analyses of statements in the motivation survey collected from the third-year and second-year cohorts

a)

	Component		
	1	2	3
q1	.757	.294	-.166
q2r	-.016	-.110	.879
q3	.125	.759	-.207
q4	.715	.397	-.254
q5r	.331	.802	-.021
q6	-.052	.106	.847
q7	.857	.030	-.036
q8	.473	.571	.096
q9	-.179	.076	.822
q10	.162	.841	.232
q11	.832	.200	.040
q12r	-.035	-.162	.862
q13	.787	.283	-.087
q14r	.205	.760	-.101

b)

Component*	Third-year Statements
1	q1 q4 q7 q11 q13
2	q3 q5r q8 q10 q14r
3	q2r q6 q9 q12r

	Component			
	1	2	3	4
q1	.810	.082	-.015	-.094
q2r	.237	.262	.464	.629
q3	.079	.860	.195	.066
q4	.724	.294	-.026	-.280
q5r	.036	.541	-.312	.484
q6	-.010	.108	.828	-.161
q7	.234	.746	.292	.157
q8	-.156	.134	.854	.216
q9	.770	-.225	-.138	.047
q10	-.016	.848	.107	.196
q11	.697	.379	-.134	.009
q12r	-.098	.132	.769	.380
q13	.734	-.005	.069	.340
q14r	-.096	.178	.130	.698

Component	Second-year (semester 1) Statements
1	q1 q4 q9 q11 q13
2	q3 q5r q7 q10
3	q6 q8 q12r
4	q2r q14r

	Component		
	1	2	3
q1	.878	.025	-.088
q2r	-.210	.081	.829
q3	.404	.654	-.154
q4	.870	.130	-.186
q5r	-.020	.866	.134
q6	.018	.040	.899
q7	.548	.441	.211
q8	.004	.084	.900
q9	.777	-.037	-.012
q10	.241	.893	.135
q11	.791	.270	-.083
q12r	-.077	.149	.895
q13	.848	.133	.033
q14r	.012	.859	.155

Component	Second-year (semester 2) Statements
1	q1 q4 q7 q9 q11 q13
2	q3 q5r q10 q14r
3	q2r q6 q8 q12r

Note: *Statements were grouped into the same component, if a component loading was 0.5 or more (see left table outputs (a) from factor analyses). The right tables (b) show a summary of statements that were grouped based on the outcomes of the factor analyses.

3.1.5 Observational protocol

Evidence supporting the content assessed by the protocol was addressed by selecting a protocol that had been used previously in a related study (Chambers and Geissberger, 1997) (see Chapter 2, section 2.3.5). To check the response process, the protocol was trialed with several fifth year students and it was then modified. Some codes and definitions were modified from the original protocol. Two training sessions, including calibration procedures, were conducted involving three observers to ensure the internal structure of observational codes. In the two sessions, the percentage of agreement with the master protocol was calculated to be 90% in the first session and 80% one week later. Prior to conducting data analysis, observation codes that observers assigned during the cavity preparation exercise were rechecked by the candidate with the video-record and these were 90% agreement.

In summary, with respect to construct validity, the current study outlines five possible sources of evidence (Beckman and Cook, 2007) to support the interpretation of assessment results (see Chapter 2, Table 2.2). As a result of the availability of data and limited feasibility of access to all sources of evidence, only content, response process and internal structure, were addressed for the psychometric tests, written exercises, cavity preparation exercises, the motivation survey and the observational protocol. Overall, the approaches used in the current study displayed acceptable construct validity for content and response process sources. It should be noted that the reliability coefficients for some assessments were relatively low (less than 0.7), ie written exercises (section 3.1.2) and cavity preparation exercises (section 3.1.3). What constitutes acceptable values for reliability coefficients depends on the purpose of assessment. It has been suggested that values in the range of 0.7-0.79 (Downing, 2004) should be expected for ‘formative or summative classroom-type assessment, created and administered by local faculty’. For shorter tests given in class, the reliability may be lower.

In the current study, the written exercise was designed as a short test for assessing knowledge about cavity preparation exercises. Although its reliability was relatively low, it did provide additional information about students’ learning of declarative knowledge relating to the cavity preparation exercises. For the cavity preparation exercises themselves, the reliability coefficient for assessment was lower than described for a key performance indicator. Therefore, the final grades for the exercises were assigned by three examiners following discussion and reaching a consensus. For the motivation survey, the reliability was estimated using factor analysis. In general, most of the statements were grouped into components similar to the original subscales. However, there were some statements that were grouped under different components, eg q7 and q8. This suggests that the characteristics of participants in the current study differed to some extent from those in a previous study (McAuley et al., 1989). One explanation may be that the sample included in the current study was relatively small compared with the previous study. This limitation needs to be considered when using this survey in a dental context.

In the following three chapters, detailed information about the results of the study will be provided in relation to the research questions (see Chapter 1, section 1.6). Chapter 4 will present results on consent rates and demographic characteristics of participants. In addition, Chapter 4 will provide results on the relationship between abilities, motivation and performance in cavity preparation exercises. Chapter 5 will present results on differences in performance and thinking processes of students at each end of the performance range. Finally, Chapter 6 will present results about perceptions and learning experiences during the DCP 2 course.

Chapter 4 - Relationship between innate abilities, motivation and performance

Ability and motivation have been identified to influence performance in various professions, eg sport and surgery. However, due to a lack of explicit theoretically-based design in previous studies (see Chapter 1, section 1.5), there have been inconsistent findings about the factors that influence performance in dentistry. To clarify the relationship between factors related to skill acquisition, eg ability (Ackerman, 1988) and motivation (Kanfer, 1990), and performance in dentistry, the current study was conducted during an operative technique course (see Chapter 2, section 2.1). It involved two cohorts of students from the third and second years of the Adelaide dental program. Various instruments (see Chapter 2, section 2.3) were used to assess these factors, eg psychometric tests and a motivation survey (Ryan, 2001), and to clarify how they influenced the outcomes of a cavity preparation exercise.

In this chapter, results of the consent rates and demographic data of participants for both cohorts will be provided. The remainder of the chapter will present the relationship between innate abilities and motivation and performance in dentistry. The results will be provided according to the sequence that the study was conducted, ie results for the third-year cohort first and then results for the second-year cohort. Specifically, descriptive statistics for each variable, ie a) scores on ability tests, b) scores on the motivation survey, c) grades for cavity preparations, and d) grades for written exercises, will be described. Finally, regression models will be presented to show the relationships between variables.

4.1 Consent rates

Seventy-four (85%) third-year students and 53 (72%) second-year students were recruited based on a range of inclusion and exclusion criteria (Chapter 2, section 2.1.6).

4.2 Demographic data of participants

For both cohorts, over half were female. The majority were right hand dominant. The mean age was 21 years (Table 4.1).

Table 4.1 Summary of demographic data of the third-year and second-year cohorts

	Third-year (n=74)		**Second-year (n=53)**	
	n	**%**	**n**	**%**
Sex				
Male	33	45	25	47
Female	41	55	28	53
Handedness				
Left	8	11	3	6
Right	66	89	50	94
Age	**Mean (range)**		**Mean (range)**	
	21 (19-26)		21 (19-25)	

4.3 Scores on psychometric tests

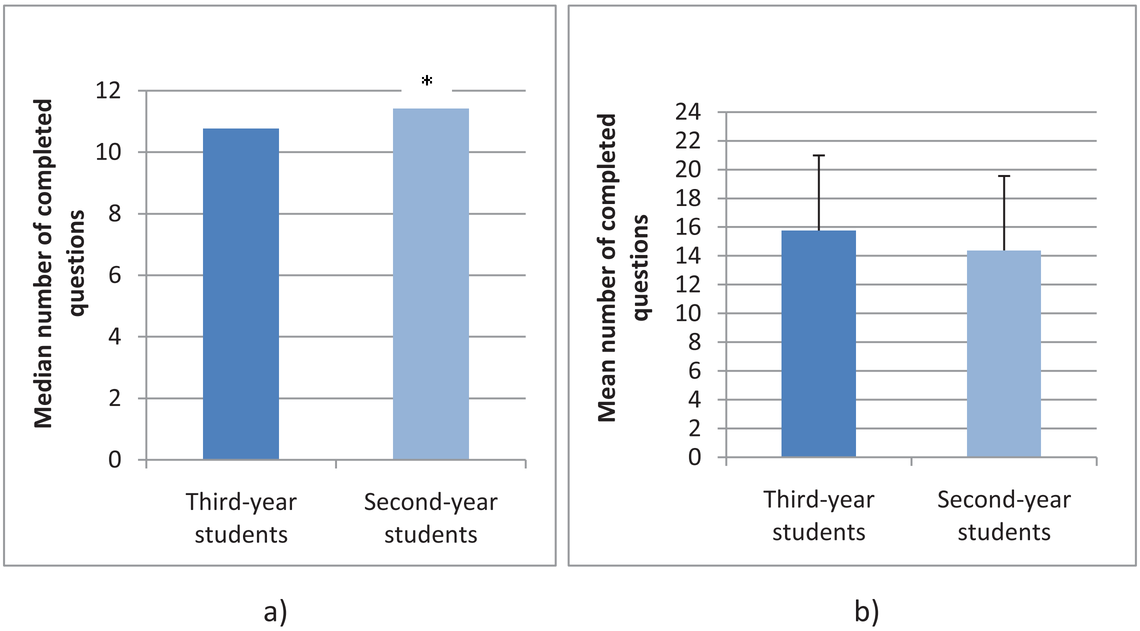
Participants from both cohorts obtained higher scores than reference groups on all psychometric tests (Table 4.2). For the Mental Rotation, Digit Modalities and Inspection Time tests, the cohort scores were significantly higher ($p<0.05$). As there were only median values available for the Raven, Tweezer and MacQuarrie tests for the reference groups, comparisons between reference groups and study samples were limited. Analyses showed that the second-year cohort outperformed the third-year cohort on the Raven, Digit and Dotting tests, whereas the third-year cohort outperformed the second-year cohort on the Tweezer test ($p<0.05$) (Figures 4.1 - 4.3). Due to differences in the levels of ability and stages of psychomotor learning, the results from both cohorts were not combined for subsequent data analysis.

Table 4.2 Comparison of ability scores in third-year and second-year cohorts with relevant reference groups

Measured ability	Tests	Unit	Reference			3rd yr (n=74) (2007)		2nd yr (n=53) (2008)	
			n	Mean (SD)	P50	Mean (SD)	P50	Mean (SD)	P50
Cognitive	Raven's Advances Progressive Matrices	score	58[1]	-	9	-	11	-	12
Cognitive	Mental Rotation test	score	636[2]	10.8 (5)	-	15.8* (5.2)	-	14.4 (5.2)	-
Perceptual speed	Digit Modalities	score	830[3]	61.9 (10.2)	-	68.9* (10.7)	-	74.5 (12.3)	-
Perceptual speed	Inspection Time	millisecond	218[4]	64 (17.3)	-	43.5* (11.2)	-	44.1 (12.6)	-
Psychomotor	Tracing	score	2000[5]	-	31	-	36.5	-	39
Psychomotor	Tapping	score	2000[5]	-	38	-	50.5	-	51
Psychomotor	Dotting	score	2000[5]	-	20	-	22	-	24
Psychomotor	Tweezer	minutes	-[6]	-	5.4	-	5.5	-	6.3

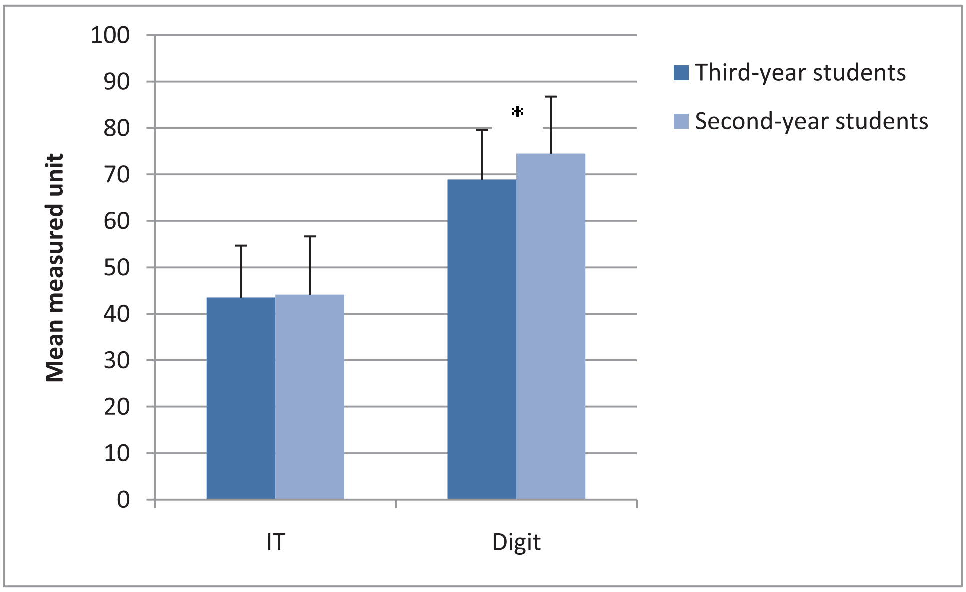
Note: - = data not available, *$p<0.05$ (t-test), SD = standard deviation, P50 = median

1. Raven's Progressive Matrices: 18-22 years olds (Raven et al., 1998)
2. Mental Rotation test: university students (Peters et al., 1995)
3. Digit Modalities test: 18-24 year olds (Smith, 1982)
4. Inspection Time: university students (Burn and Nettelbeck, 2005)
5. MacQuarrie tests: > 16 year olds (MacQuarrie, 1953)
6. O'Connor Tweezer: Factory employees (O'Connor, 1998)



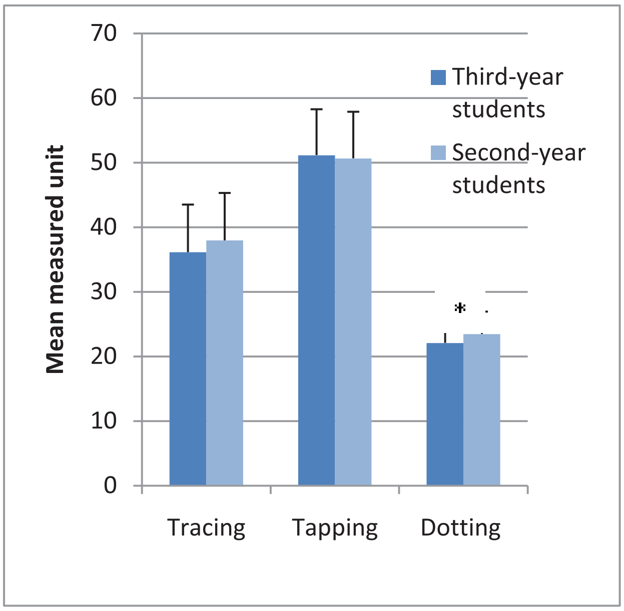
*p<0.05 (Mann-Whitney U test), second-year outperformed third-year students (standard deviations as indicated)

Figure 4.1 Difference in results between the third-year and second-year cohorts for cognitive ability tests: a) Raven's Advanced Progressive Matrices and b) Mental Rotation test

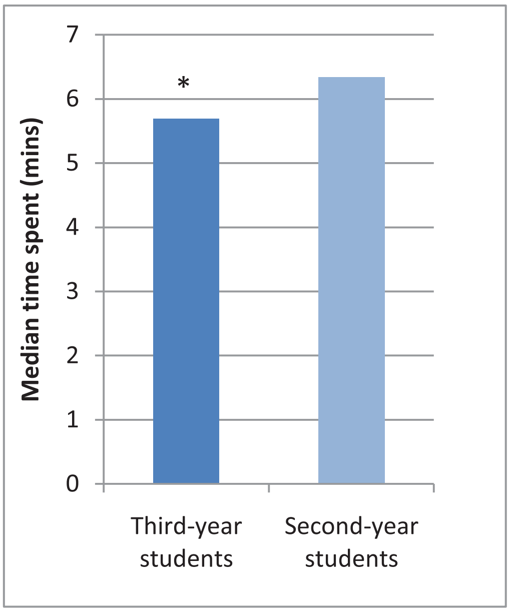


*p<0.05 (t-test), second-year outperformed third-year students (standard deviations as indicated)

Figure 4.2 Difference in results between the third-year and second-year cohorts for perceptual speed ability tests: Inspection Time (IT) and Digit Modalities test



a)

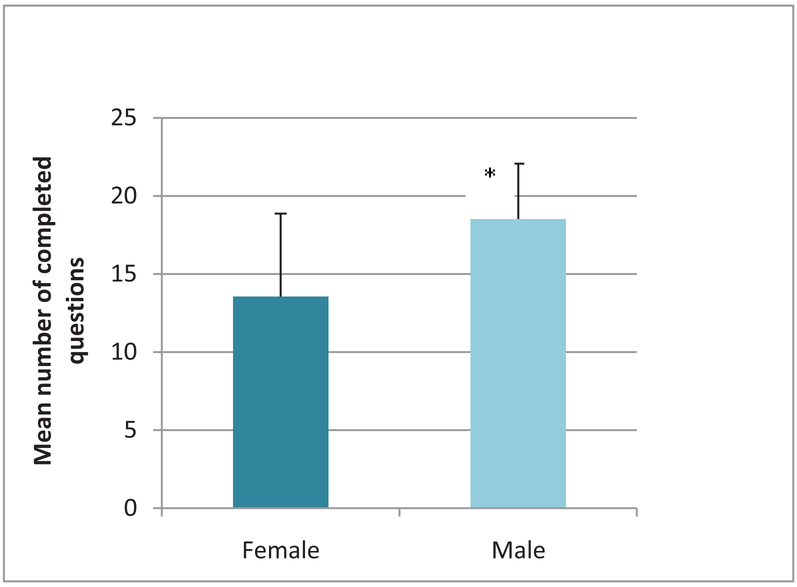


b)

a) *p<0.05 (t-test), second-year outperformed third-year students (standard deviations as indicated)
b) *p<0.05 (Mann-Whitney U test), third-year outperformed second-year students

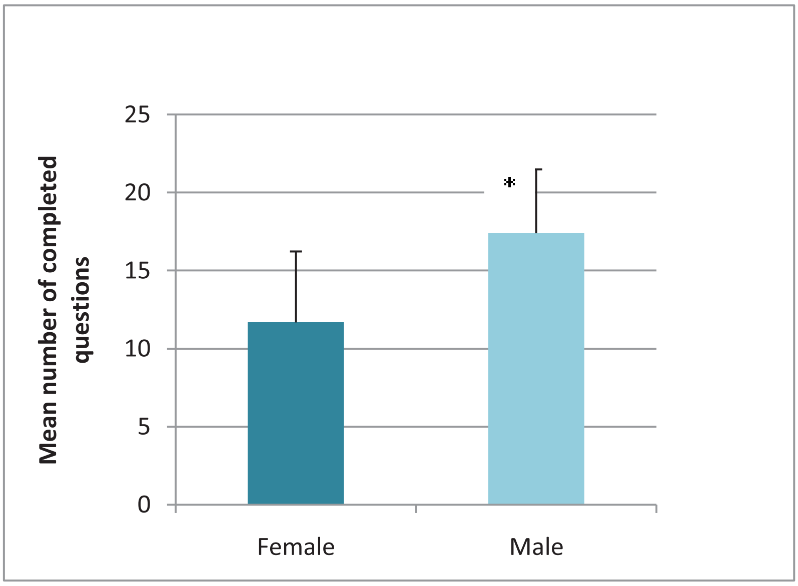
Figure 4.3 Difference in results between the third-year and second-year cohorts for psychomotor ability tests: a) Tracing, Tapping, Dotting and b) O'Connor Tweezer test

General linear models were used to analyse the effect of selected factors on the scores obtained in the tests, eg handedness and sex. As there were only small numbers of left-handed students in both cohorts (Table 4.1), only sex was included as a factor in the data analyses. The results showed that there was a significant interaction effect of sex on the scores in the psychometric tests. Male students significantly outperformed females in the Mental Rotation tests in both cohorts (p<0.05) (Figures 4.4 and 4.5). Detailed information about sex differences in scores obtained for the psychometric tests is given in Appendix 19.



*p<0.05 (t-test), males outperformed females (standard deviations as indicated)

Figure 4.4 Difference in results between third-year males and females for Mental Rotation test



*p<0.05 (t-test), males outperformed females (standard deviations as indicated)

Figure 4.5 Difference in results between second-year males and females for Mental Rotation test

4.4 Grades for written exercises

4.4.1 Grades of the third-year cohort

Grades obtained for the written exercise by third-year students indicated that more than 90% of the students achieved a Satisfactory or Good grade in Question 1 of the exercise (Table 4.3). This result showed that at the beginning of the third year, these students could accurately identify which burs were needed to prepare an MOD cavity and this was supported by providing an appropriate rationale for their selection. However, only one-third of the students could draw an appropriate outline of the cavity that they planned to cut in the 36 Frasaco™ tooth (Question 2) and only approximately 40% provided an adequate rationale for their cavity design (Question 3).

Table 4.3 Summary of grades obtained for the written exercise by the third-year cohort

Question	Grades								Total
	U		UR		S		G		
	n	%	n	%	n	%	n	%	
1	2	3	N/A	N/A	49	66	23	31	74
2	15	20	36	49	23	31	0	0	74
3	45	61	N/A	N/A	29	39	N/A	N/A	74

N/A = not applicable - no grades assigned in this category, see grading systems in Chapter 2, section 2.3.2
Note: Grades: U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory, G = Good
Question 1 - discuss the specific burs needed to prepare the cavity
Question 2 - draw an outline of the cavity design on a diagram of the relevant tooth
Question 3 - discuss the rationale for the cavity design

4.4.2 Grades of the second-year cohort

There were no significant differences in the distribution of grades obtained for the written exercises at the end of semester 1 or 2 (Table 4.4). The results from the GEE revealed that there was no significant change in grades over time for any of the questions relating to the exercise when individual matched data were analysed ($p>0.05$).

Table 4.4 Summary of grades obtained for the written exercise by second-year students during different stages of learning

Question		Grades								Total*
		U		UR		S		G		
		n	%	n	%	n	%	n	%	
1	Semester 1	21	40	N/A	N/A	28	53	4	7	53
	Semester 2	20	38	N/A	N/A	28	54	4	8	52
2	Semester 1	10	19	25	47	17	32	1	2	53
	Semester 2	15	29	17	33	19	37	1	1	52
3	Semester 1	23	43	N/A	N/A	30	57	N/A	N/A	53
	Semester 2	19	37	N/A	N/A	33	63	N/A	N/A	52

*One student did not attend class.

Note: Grades: U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory, G = Good

Question 1 - discuss the specific burs needed to prepare the cavity

Question 2 - draw an outline of the cavity design on a diagram of the relevant tooth

Question 3 - discuss the rationale for the cavity design

4.5 Grades for cavity preparations

Grades received for cavity preparations were used to determine the performance of students and, in turn to reflect their psychomotor skills.

4.5.1 Performance of the third-year cohort

Only approximately one-third of students in the third-year cohort (36%) obtained satisfactory or good grades for the cavity preparation exercise at the commencement of the DCP 3 course, whereas 47 students (64%) obtained an unsatisfactory grade (Table 4.5).

Table 4.5 Summary of grades obtained for the cavity preparation exercise by third-year students at different stages of their learning

Stage of learning	Grades								Total*
	U		UR		S		G		
	n	%	n	%	n	%	n	%	
End of semester 1 2nd year (2006)	31	47	24	36	11	17	0	0	66
End of semester 2 2nd year (2006)	15	23	21	32	27	41	3	4	66
Commencement of semester 1 3rd year (2007)	23	31	24	33	26	35	1	1	74

*Some students did not participate when they were in second year.
Note: Grades: U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory, G = Good

Using a Generalized Estimating Equation (GEE) to assess changes in grades over time within an individual (matched data), it was found that grades obtained for the cavity preparation exercise generally improved significantly from semester 1 to semester 2 in the second year. However, there was no difference in grades obtained for the exercise between second year and third year.

4.5.2 Performance of the second-year cohort

The results from GEE indicated that overall, students' performance improved over time (Table 4.6) within an individual (matched data) ($p<0.05$), from prior to learning to after one and then two semesters of learning. This can be seen from the increasing percentage of students who obtained satisfactory grades over time. At the end of semester 1 (SEM1), among the students who obtained U and UR grades, most of the errors (78%) in their MOD preparations were related to inappropriate cutting of proximal boxes. For example, there were problems with the depth of the gingival floor, or the shape or position of the proximal boxes (Table 4.7). Similarly, these errors were found in most of the unsatisfactory and unsatisfactory but redeemable cavities prepared at the end of semester 2 (SEM2). Other issues included deep and large occlusal cavities or a shallow occlusal cavity, ie less than two millimeters. Although students achieved better grades overall with time, which is evident by a decreased percentage of students who obtained U and UR grades in semester 2, the errors produced involved similar aspects of cavity preparation, ie deficiencies in the proximal boxes.

Table 4.6 Summary of grades obtained for the cavity preparation exercise by second-year students at different learning stages

Stage of learning	Grades								Total*
	U		UR		S		G		
	n	%	n	%	n	%	n	%	
Pre-learning	34	65	12	23	4	8	2	4	52
End of semester 1	24	45	26	49	3	6	0	0	53
End of semester 2	17	33	16	31	17	33	2	3	52

*Some of students did not attend class.
Note: Grades: U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory, G = Good

Table 4.7 Summary of errors in the cavity preparation exercises completed by the second-year cohort at the end of semesters 1 and 2

Items	Semester 1 Frequency (n=50)*	%	Semester 2 Frequency (n=33)*	%
[1]**Deep & Large occlusal cavity**	7	14	3	9
[2]**Shallow occlusal cavity**	4	8	3	9
[3]**Inappropriate proximal boxes**	39	78	27	82

*number of students
Note: [1]Depth more than 2mm; compromised cusp structures or pulp
[2]Depth less than 2mm
[3]Divergent proximal boxes toward occlusal portions; box does not cover contact areas

Despite differences in learning activities between the cohorts in terms of the sequence and number of learning activities (see Chapter 2, section 2.2), specifically in semester 2 of the course, there was no difference in the pattern of grades students obtained for the exercise. While the third-year cohort completed learning activities in relation to an MOD cavity preparation during weeks 3 and 5, the second-year cohort completed these activities during weeks 6 and 9 (see Appendices 5 and 6). While there was a small difference in the number of weeks of learning prior to the cavity preparation activity used in this study, ie weeks 10 or 11, it was not expected that this could make much different between the cohorts. This was supported by a similar pattern of performance in both cohorts.

To identify the pattern of errors in students' cavity preparations at an individual level across different stages of learning, the types of errors were compared at different time periods (Table 4.8). As students completed the cavity preparation exercise before gaining an understanding of cavity design in the pre-learning stage, the comparison of errors was only made between SEM1 and SEM2. The results showed that almost half of the students produced similar errors in the exercise in each semester. It was also noted that 35% of students showed improved accuracy in their cavity preparations. About 45% of the students still had errors in creating appropriate proximal boxes.

Table 4.8 Pattern of errors in cavity preparation exercises between semesters 1 and 2 (intra-individual level)

Pattern of changes	Frequency (n=51)*	%
[1]Similar errors	23	45
[2]Different errors	10	20
[3]More accurate aspects	18	35

*number of students
Note: [1]Cavities had similar types of errors in semester 1 and 2
[2]Cavities had different types of errors in semester 1 and 2
[3]Cavities had improved, fewer errors in semester 2

In summary, there was evidence to support the development of psychomotor skills by dental students involving a cavity preparation exercise, with grades improving and fewer errors being made over time. It is clear that the range of learning activities provided in each year, supported improvement in the quality of students' outcomes, despite some variations in the sequence of activities between the different cohorts.

4.6 Scores on motivation survey

For both cohorts, students indicated that they had put considerable effort into the cavity preparation exercise (mean=5.7). The students also noted that the exercise was useful (mean score=6.2) for practising cavity preparation skills (Table 4.9). However, the second-year cohort reported a higher level of pressure during the exercise in both semesters than the third-year cohort ($p<0.05$). This pressure significantly decreased from semester 1 to semester 2 ($p<0.05$).

Table 4.9 Summary statistics for perceived effort, usefulness and pressure associated with the cavity preparation exercise in third-year and second-year cohorts

Subscales	Third-year	Second-year (Semester 1)	Second-year (Semester 2)
	Mean (SD)	Mean (SD)	Mean (SD)
Effort	5.7 (0.9)	5.6 (0.7)	5.4 (0.8)
Usefulness	6.2 (0.7)	6.1 (0.6)	5.9 (0.7)
Pressure	3.8 (1.3)	5.2 (0.9)*	4.7 (1.0)*

Note: SD = standard deviation, Likert scales: 1 = not at all true, 4 = somewhat true and 7 = very true, *$p<0.05$ (t-test), the second-year cohort (both semesters) reported higher scores than the third-year cohort, the second-year cohort (semester 2) reported lower scores than in semester 1.

4.7 Relationship between ability and performance

4.7.1 Results of the third-year cohort

Ordinal regression was used to explore relationships between students' ability and performance on the 36 MOD amalgam cavity preparation exercises. Scores on psychometric tests were independent variables and grades obtained for the cavity preparation exercise were the dependent variable. A main effect of each test's score was put into the regression model as well as an interaction effect of sex. The results presented in this section include only those models with significant main effects and/or an interaction effect. A significant association was found between one of the psychomotor ability tests, the Tapping subtest, with grades obtained by third-year students for the cavity preparation exercise. A significant negative association was noted between scores on the Tapping subtest (Tapping) and sex, and grades obtained for cavity preparation, holding all other variables constant (Table 4.10). However, there was an interaction effect of Tapping and sex on grades. To clarify the influence of sex and Tapping ability on grades for the cavity preparation, the students were divided into two groups according to the scores obtained for the Tapping subtest. One standard deviation below and one above the mean were used as cutoff points to determine ‘lower score’ and ‘higher score’ Tapping subgroups respectively. For the lower score Tapping sub-group, there was no difference between the sexes in grades (Table 4.11). However, there was a difference between the sexes for the higher score Tapping sub-group. Females in this group were 4.68 times more likely to display a higher level of performance in their cavity preparation than males ($p<0.05$). There were no other significant relationships between the remaining psychometric tests and grades for the cavity preparation.

Table 4.10 Results of regression analysis of factors associated with grades obtained for cavity preparations among third-year students

Variables		Coefficient (Standard Error)	95% Confidence Limits	
Tapping*		-0.09 (0.05)	-0.19	-0.00
Sex*	Female	-7.22 (3.44)	-13.96	-0.47
	Male (ref.)	.	.	.
Tapping-Sex*	Female	0.15 (0.07)	0.02	0.28
	Male (ref.)	.	.	.

*p<0.05, n=74

Note: ref. = reference group for comparative analysis

Table 4.11 Odds ratios of grades obtained for cavity preparations between sexes in relation to scores obtained for the Tapping subtest among third-year students

Comparison		Odds ratios (Standard error)	95% Confidence Limits	
Lower score tapping (score<=44.03)	Female	0.55 (0.35)	0.16	1.92
	Male (ref.)	.	.	.
Higher score tapping* (score>=58.23)	Female	4.68 (3.10)	1.28	17.16
	Male (ref.)	.	.	.

*p<0.05

Note: ref. = reference group for comparative analysis

4.7.2 Results of the second-year cohort

A Generalised Estimating Equation (GEE) with multinomial distribution and cumulative logit link was used to assess changes in grades over time and interactions with ability scores. Again, a main effect of each test's score was put into the model as well as interaction terms with time. If an interaction was not significant, it was removed and the model was estimated with main effects only. Sex and age were included in the models as covariates. The relationship between ability and performance on cavity preparations was analysed in relation to a number of cavity preparation exercises, ie a) three learning stages, including pre-learning (PRE), end of semester 1 – week 11 (SEM1) and 2 (SEM2) and b) seven learning stages including selected cavity preparation exercises completed during semester 1 (see details in section 2.3.3) Firstly, the exercise was considered at three time periods, and the results showed that, overall, there was an improvement in the grades over the three learning stages. However, the change in grades over time was influenced by scores obtained for one of the cognitive ability tests, the Mental Rotation test (MRT), as shown in Table 4.12. In addition, a main effect of tracing scores was noted, indicating that high tracing scores were associated with higher grades overall (p<0.05).

Table 4.12 Results of regression analysis of factors associated with grades obtained for cavity preparations among second-year students

Variables		Coefficient (Standard Error)	95% Confidence Limits	
Time*	Semester 1	-2.25 (1.02)	-4.25	-0.24
	Semester 2	-3.34 (1.22)	-5.74	-0.94
	Pre-learning (ref.)	.	.	.
MRT*		-0.22 (0.07)	-0.37	-0.08
MRT-Time*	Semester 1	0.21 (0.08)	0.06	0.36
	Semester 2	0.36 (0.09)	0.19	0.53
	Pre-learning (ref.)	.	.	.
Tracing*		0.07 (0.02)	0.02	0.12
Sex	Female	-0.16 (0.52)	-1.17	0.86
	Male (ref.)	.	.	.
Age		0.23 (0.17)	-0.10	0.56

*p<0.05, n=52

Note: ref. = reference group for comparative analysis

A significant negative association was noted between the independent variables, ie time and scores on MRT, and grades obtained for the cavity preparations, holding all other variables constant. However, there was an interaction between MRT and time (p<0.05), which is referred to as MRT-Time in Table 4.12. This indicates that the change in grades over time differed for those with different levels of scores on the MRT. Again, one standard deviation below and one above the mean were used as cutoff points to determine ‘lower score’ and ‘higher score’ MRT sub-groups respectively. Within the lower MRT sub-group, there were no significant differences in the grades between time periods. However, there was a difference in grades obtained over time for the higher MRT sub-group (Table 4.13). Within this group, the odds of achieving a higher grade (a positive coefficient value) at SEM1 by comparison with PRE increased by 6.56 times ($p<0.05$). The odds increased by 5.72 times between SEM1 to SEM2 ($p<0.05$). There was also a significant difference in grades between SEM2 and PRE ($p<0.05$). However, the estimated values (OR = 37.49, 95%CI: 10.33, 136.08), indicate a broad confidence interval associated with the relatively small sample size. In summary, there was evidence of a general improvement in grades over time for those with higher MRT scores compared with those with lower MRT scores.

Table 4.13 Odds ratios of grades obtained for cavity preparations in relation to scores obtained for the MRT and Tracing test among second-year students

Comparison		Odds ratios (Standard error)	95% Confidence Limits	
Low MRT (score <=9.21)	Semester 1	0.74 (0.33)	0.31	1.79
	Pre-learning (ref.)	.	.	.
	Semester 2	0.94 (0.51)	0.33	2.70
	Pre-learning (ref.)	.	.	.
	Semester 2	1.28 (0.53)	0.56	2.89
	Semester 1 (ref.)	.	.	.
High MRT* (score >=19.55)	Semester 1	6.56 (4.26)	1.84	23.40
	Pre-learning (ref.)	.	.	.
	Semester 2	37.49 (24.66)	10.33	136.08
	Pre-learning (ref.)	.	.	.
	Semester 2	5.72 (2.91)	2.10	15.53
	Semester 1 (ref.)	.	.	.
Tracing*	High (score >=45.28)	2.76 (0.99)	1.36	5.60
	Low (score <=30.60) (ref.)	.	.	.

*p<0.05
Note: ref. = reference group for comparative analysis

Data collected for selected cavity preparation exercises that were completed during semester 1 of the DCP 2 course were included in the analysis (see details in section 2.3.3) in relation to three time periods, ie PRE, SEM1 and SEM2. These consisted of occlusal cavity exercises in weeks 5 and 6, and MOD cavity designs in weeks 9 and 10. A significant negative association was noted between time (pre-learning) and grades obtained for the cavity preparations and also scores on the MRT, holding all other variables constant. However, there was also an interaction effect of MRT and time as shown in Table 4.14. As there may be potential influences of other psychomotor ability measures on the scores for the Tracing subtest based on the results of regression analyses between those variables, scores on the Dotting tests were also included in the model. However, a main effect of Tracing was still significant ($p<0.05$), indicating a positive association with the grades.

Table 4.14 Results of regression analysis of factors associated with grades obtained for cavity preparations among second-year students

Variables		Coefficient (Standard Error)	95% Confidence Limits	
Time*	Pre-learning	3.44 (1.24)	1.01	5.87
	Week 5[a] semester 1	0.91 (1.22)	-1.49	3.30
	Week 6 semester 1	0.87 (1.33)	-1.74	3.48
	Week 9 semester 1	1.19 (1.02)	-0.80	3.18
	Week 10 semester 1	0.65 (1.06)	-1.42	2.72
	Week 11 semester 1	1.28 (0.99)	-0.66	3.23
	Week 11 semester 2 (ref.)	.	.	.
MRT*		0.20 (0.07)	0.07	0.34
MRT-Time*	Pre-learning	-0.39 (0.09)	-0.55	-0.22
	Week 5[a] semester 1	-0.12 (0.07)	-0.27	0.02
	Week 6 semester 1	-0.15 (0.08)	-0.31	0.00
	Week 9 semester 1	-0.16 (0.07)	-0.29	-0.02
	Week 10 semester 1	-0.14 (0.07)	-0.28	-0.00
	Week 11 semester 1	-0.18 (0.07)	-0.32	-0.03
	Week 11 semester 2 (ref.)	.	.	.
Dotting		0.06 (0.36)	-0.01	0.13
Tracing*		0.04 (0.02)	0.01	0.07
Sex*	Female	0.70 (0.35)	0.02	1.38
	Male (ref.)	.	.	.
Age		0.08 (0.10)	-0.10	0.27

*$p<0.05$, [a]number of weeks in the course, does not include mid-semester break (2 weeks)
Note: ref. = reference group for comparative analysis

To clarify the relationship between MRT scores and grades obtained for cavity preparation exercises at seven different time periods, lower and higher MRT score subgroups were identified using the same cut off points as noted previously. While there were no significant differences in grades among the time periods within the lower MRT sub-group, significant changes in the grades were noted over time within the higher MRT sub-group. As shown in Table 4.15, different time periods were used as a reference for comparisons based on the stage of learning. The results showed that within the higher MRT sub-group, grades obtained for SEM2 were higher than for all other time periods, and PRE grades were the lowest ($p<0.05$) (Table 4.15). However, there was no significant difference in the grades obtained for the exercises in weeks 5, 6, 9, 10 and SEM1 ($p>0.05$).

Table 4.15 Odds ratios of grades obtained for cavity preparations at different time periods in relation to scores obtained for the MRT test among second-year students

Comparison		Odds ratios (Standard error)	95% Confidence Limits	
High MRT* (score >=19.55)	Week 5[a] semester 1	13.56 (8.12)	4.19	43.85
	Week 6 semester 1	7.46 (5.35)	1.83	30.39
	Week 9 semester 1	9.05 (6.16)	2.38	34.38
	Week 10 semester 1	7.45 (4.67)	2.18	25.47
	Week 11 semester 1	6.92 (4.41)	1.98	24.12
	Week 11 semester 2	59.98 (39.11)	16.71	215.29
	Pre-learning (ref.)	.	.	.
High MRT*	Week 6 semester 1	0.55 (0.17)	0.29	1.01
	Week 9 semester 1	0.67 (0.21)	0.36	1.24
	Week 10 semester 1	0.55 (0.22)	0.25	1.21
	Week 11 semester 1	0.51 (0.26)	0.19	1.37
	Week 11 semester 2	4.42 (1.91)	1.89	10.31
	Week 5 semester 1 (ref.)	.	.	.
High MRT*	Week 9 semester 1	1.21 (0.39)	0.64	2.29
	Week 10 semester 1	0.99 (0.45)	0.41	2.42
	Week 11 semester 1	0.93 (0.52)	0.31	2.79
	Week 11 semester 2	8.04 (3.74)	3.23	20.02
	Week 6 semester 1 (ref.)	.	.	.
High MRT*	Week 10 semester 1	0.82 (0.40)	0.32	2.14
	Week 11 semester 1	0.76 (0.46)	0.23	2.49
	Week 11 semester 2	6.62 (3.38)	2.43	18.03
	Week 9 semester 1 (ref.)	.	.	.
High MRT*	Week 11 semester 1	0.93 (0.38)	0.41	2.08
	Week 11 semester 2	8.05 (4.40)	2.75	23.55
	Week 10 semester 1 (ref.)	.	.	.
High MRT*	Week 11 semester 2	8.67 (5.00)	2.79	26.89
	Week 11 Semester 1 (ref.)	.	.	.

*$p<0.05$, [a]number of weeks in the course, does not include mid-semester break (2 weeks)
Note: ref. = reference group for comparative analysis

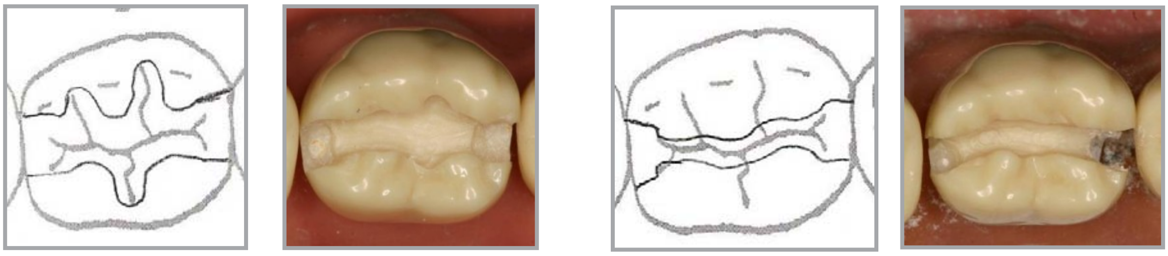
4.8 Relationship between written exercise grades and performance

The relationship between motor learning constructs included in a written exercise and performance on an MOD cavity preparation was determined using Chi-square tests. The grades obtained for the exercise could be related to two motor learning constructs. Specifically, Question 1 required students to discuss which specific burs were needed for preparing the tooth, which relates to desired performance (DP), ie knowledge about processes needed for the cavity preparation exercise (see Chapter 1, section 1.4.3). Questions 2 and 3 required students to draw the cavity design on a diagram and to discuss its rationale, both of these being related to desired outcome (DO). The results showed that for the third-year cohort there was a significant association between grades obtained for Question 2 and grades obtained for the cavity preparation ($p<0.05$) ($\chi^2=12.1$, $df=4$) (Table 4.16). However, there was no significant association between other questions and grades obtained. Figure 4.6 shows an example of sketched diagrams and prepared cavities produced by two students which demonstrate close matches between the sketches and the actual cavity preparations. In contrast, for the second-year cohort, a signicant association was only found between Question 3, which required students to discuss the rationale for their sketch and grades obtained for an MOD cavity preparation ($p<0.05$). Students who could explain critical characteristics required for the cavity sketch tended to obtain higher grades in the cavity preparation exercise compared with those who indicated fewer characteristics of their sketch (see Appendix 12).

Table 4.16 Distribution of grades obtained for a sketch of the cavity outline in relation to grades obtained for cavity preparation

Grades for cavity preparation	Grades for a sketch of the cavity outline		
	U	UR	S+G
U	6	14	3
UR	3	15	6
S+G	6	17	14

Note: Grades: U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory, G = Good



a) b)

Figure 4.6 Examples of sketched diagrams and prepared cavities on tooth 36 produced by two students from the third-year cohort

Note: a) close match between a satisfactory sketch and a satisfactory actual outcome, and b) close match between an unsatisfactory sketch and an unsatisfactory actual outcome

4.9 Relationship between motivation and performance

For the third-year cohort, results from regression analyses demonstrated a significant positive association between the amount of effort reportedly put into the task and the grades obtained for the cavity preparation exercise ($p<0.05$) (Table 4.17). The results indicate that there were no interaction effects between effort scores and sex. Those students with higher scores on the effort subscale were more likely to perform better in cavity preparation. With one unit increase in an effort score, there was an 78% increase (exp(0.58) = 2.714^0.58 = 1.78) in the odds that an individual would get a higher grade for the exercise. There was no relationship between other subscales (pressure and value) and obtained grades. For the second-year cohort, there was a significant association of scores on the value subscale in the motivation survey with grades obtained for the cavity preparation exercise (Table 4.18). This result indicates that students who reported higher scores on the value subscale tended to show superior performance in the cavity preparation exercise than those with lower scores.

Table 4.17 Results of regression analysis of motivation – effort subscale associated with grades obtained for cavity preparations among third-year students

Variables		Coefficient (Standard Error)	95% Confidence Limits	
Effort*		0.96 (0.43)	0.12	1.81
Sex	Female	3.60 (3.02)	-2.33	9.53
	Male (ref.)	.	.	.
Effort-sex	Female	-0.53 (0.52)	-1.55	0.48
	Male (ref.)	.	.	.

*p<0.05
Note: ref. = reference group for comparative analysis

Table 4.18 Results of regression analysis of motivation – value subscale associated with grades obtained for cavity preparations among second-year students

Variable	Coefficient (Standard Error)	95% Confidence Limits	
Value*	1.05 (0.49)	-0.07	2.03

*p<0.05

4.10 Summary

In summary, the results obtained from both cohorts of the students revealed that there was a significant association between individual differences in ability and motivation with dental performance, ie preparation of an MOD cavity. Firstly, there was a positive association of psychomotor ability and cognitive ability, particularly broad content ability, with performance on the cavity preparation. This relationship varied depending on the stage of learning. In the third-year cohort, psychomotor ability measured by the Tapping test, was a significant factor in achieving a higher level of performance. In contrast, in the second-year cohort, scores on the Mental Rotation test that measured broad content as well as the Tracing test were found to be associated with a higher grade for the cavity preparations. The small sample size of students in the second-year cohort, which was smaller than the optimal number indicated by a power analysis, might explain the different findings between the two phases of the current study. Furthermore, it is acknowledged that multiple tests were performed and that some significant results would be expected by chance.

Secondly, the significant association between grades obtained for the sketch and grades obtained for the cavity preparation exercise indicates the use of desired outcome during the cavity preparation exercise. Finally, a motivation determinant related to effort was an influential factor in accomplishing a higher grade for the cavity preparation exercise. However, this relationship was noted only in the third-year cohort. From the results of the factor analysis, it is evident that some statements did not load on the same component as occurred in the original use of the survey (see Chapter 3, section 3.1.4) and in a previous study (McAuley et al., 1989). Again, differences in results from both cohorts might be explained by the small sample size (MacCallum et al., 1999) of students in the second-year cohort.

In the next chapter, results related to differences in performance and thinking processes of students at each end of the performance range will be presented. The latter aspect will be presented to clarify the use of motor learning parameters during the completion of the cavity preparation exercise.

Chapter 5 - Differences in performance and thinking processes between students at the ends of the performance range

In addition to inherited factors, eg ability, that influences learning outcomes of operative skills, the investigation of students' thinking processes while completing a task should help us to understand their knowledge and processes related to outcomes and procedures they use in completing a task. (see Chapter 1, section 1.4.3). As noted previously in Chapter 1, research into motor learning parameters has provided valuable insights into their role in supporting skill learning (Feil et al., 1994; Knight et al., 1994). Feil and Gatti's study (1993) involved practitioners and dental students and differences in the use of motor learning parameters were noted between these two groups. This suggested that students with different levels of performance might demonstrate differences in this aspect. However, little information is known about this issue. Therefore, to determine if different characteristics were evident between students who showed different levels of performance, an observational study and a qualitative study of sub-groups of students were conducted (see Chapter 2, section 2.3.5) in both phases of the current study. Although it was not possible to evaluate all processes from the beginning of learning in the third-year cohort, the findings of Phase I were useful in terms of clarifying what students had achieved from the learning activities in the DCP 2 course. Using an expert performance conceptual framework to explore performance of students in higher and lower performance sub-groups, the current study investigated the time spent in each operation (Chambers and Geissberger, 1997) (see Chapter 2, section 2.3.5) during a cavity preparation exercise. To identify students' thinking processes, a retrospective think-aloud technique was used (see Chapter 2, section 2.3.6) which involved video recordings of performance followed by interviews. Interview questions addressed motor learning parameters outlined in motor learning theory (Schmidt and Lee, 2005).

This chapter provides the results from two sub-groups of students whose performance placed them at the ends of the performance range. Observational data showing performance and motor learning parameters used during an MOD amalgam cavity preparation exercise are reported. Prior to giving detailed information about these aspects, demographic data of the sub-groups are provided.

5.1 Demographic data

This section includes demographic data from the two sub-groups of students referred to as the higher and lower performance sub-groups (see Chapter 2, section 2.1.7), in Phase I and II of the study, namely their sex and grades obtained for exercises that were also observed.

5.1.1 Third-year cohort

Twelve students, consisting of two females and ten males participated in an observational component of the study (see Chapter 2, section 2.3.5). Although the groups comprised students from 'higher' and 'lower' levels of performance, a few students from both sub-groups achieved a satisfactory grade for the MOD amalgam cavity preparation exercise completed during the data collection phase (Figure 5.1).

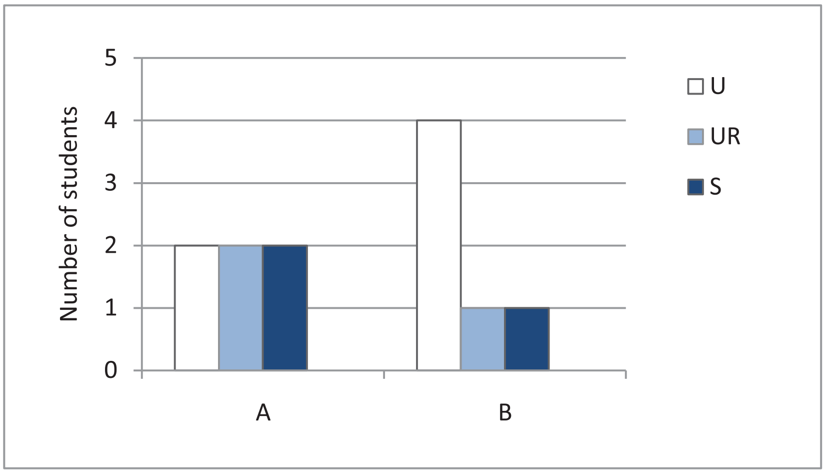


Figure 5.1 Summary of grades obtained for the 36 MOD amalgam cavity preparation exercise by two sub-groups of third-year students

Note: A = higher performance sub-group (n=6), B = lower performance sub-group (n=6)
U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory

5.1.2 Second-year cohort

5.1.2.1 Participants involved in the observational study

There were 22 students involved in the observational study, comprising 13 females and nine males. The higher performance sub-group comprised nine students (males = 3, females = 6) and a lower performance sub-group comprised 13 students (males = 6, females = 7). Figure 5.2 shows the numbers of students who participated in the observational study. These same students participated throughout the study but not all students were observed at each data collection session. As the observations were completed in laboratory sessions, approximately eight students were able to be observed in any one session (see Chapter 2, section 2.3.5).

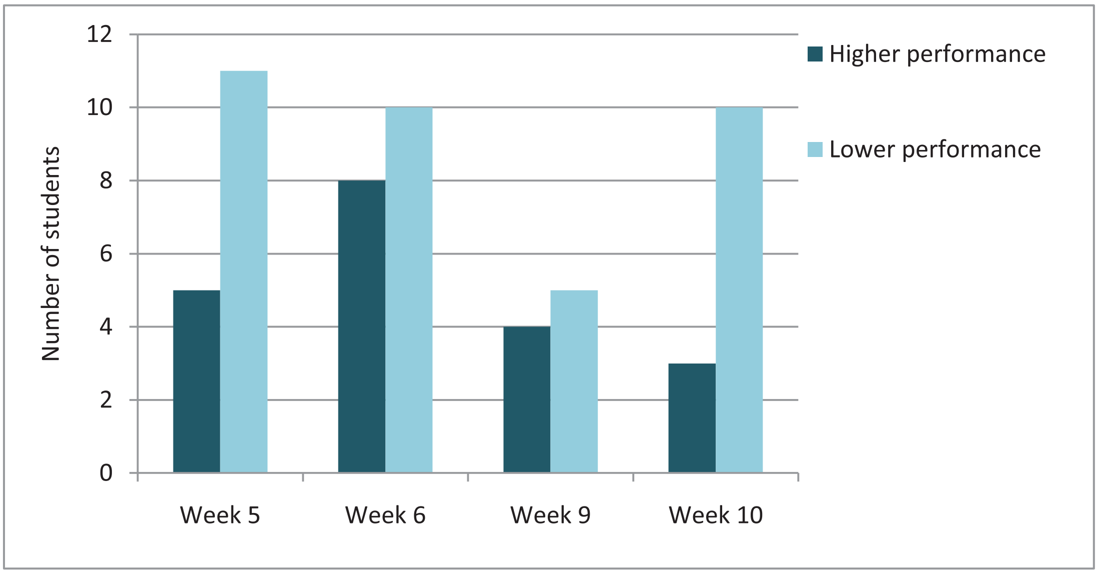


Figure 5.2 Number of students who participated in the observational study over four consecutive laboratory sessions in the second-year cohort

Note: Week 5: occlusal (GV Black for composite resin restoration)
Week 6: occlusal (GV Black for amalgam restoration)
Week 9: slot with occlusal (GV Black for composite resin restoration)
Week 10: slot with occlusal (GV Black for amalgam restoration)

Similar to Phase I, a few students obtained satisfactory grades for the cavity preparation exercises during four consecutive laboratory sessions (Figure 5.3). There was little difference in the grades obtained for the exercises between the two sub-groups except in week 10. More students in the lower performance sub-group obtained unsatisfactory grades than students in the higher performance sub-group but this finding was not significantly different ($p>0.05$).

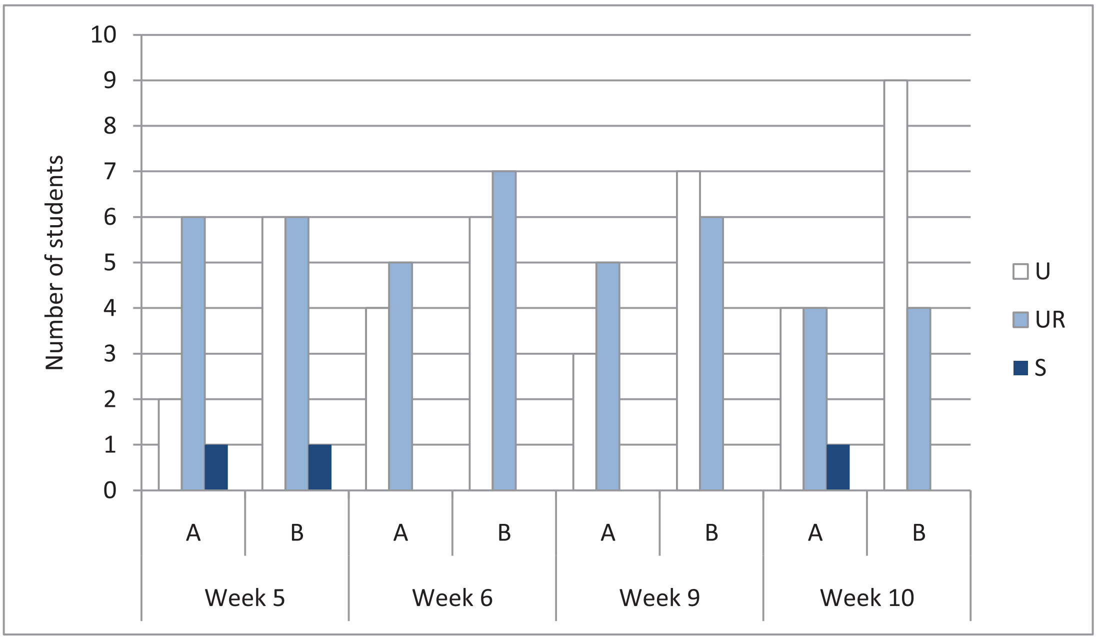


Figure 5.3 Summary of grades obtained for cavity preparation exercises by the second-year cohort over four consecutive laboratory sessions

*One student did not participate in class in week 9.

Note: A = higher performance sub-group (n=9), B = lower performance sub-group (n=13)
U = Unsatisfactory, UR = Unsatisfactory Redeemable, S = Satisfactory
Week 5: occlusal (GV Black for composite resin restoration)
Week 6: occlusal (GV Black for amalgam restoration)
Week 9: slot with occlusal (GV Black for composite resin restoration)
Week 10: slot with occlusal (GV Black for amalgam restoration)

5.1.2.2 Participants involved in interviews

There were 29 students who participated in the interview sessions, including 16 students from the higher (n=8) and lower sub-groups (n=8) and 13 students from the remainder of the class in the second-year cohort. As students were invited to participate in interviews based on their responses in written critical incident reports (see Chapter 2, section 2.3.7), the number of students varied in each interview session.

5.2 Performance during the cavity preparation exercise

In this section, detailed information about time spent and frequency of each operation by sub-groups of students (see definitions of operations in Table 2.5, Chapter 2), will be summarised. Only completed records that the candidate observed for the whole process of cavity preparation were included for data analysis.

5.2.1 Performance of the third-year cohort

5.2.1.1 Time spent and frequency of changes in operations

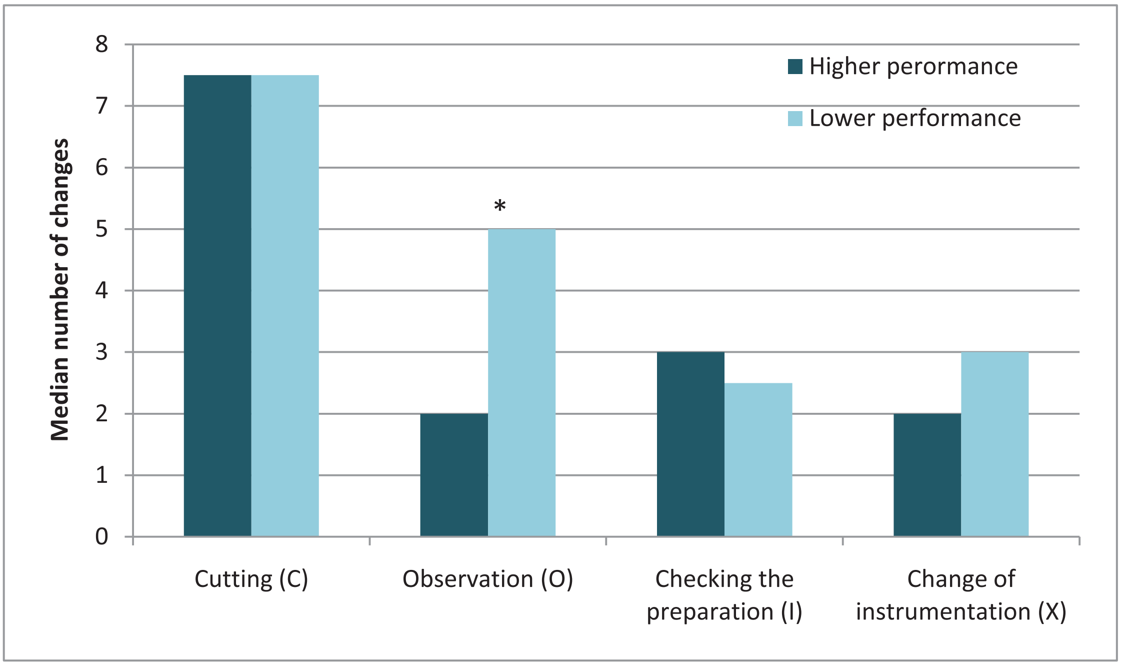
In preparing an MOD amalgam cavity, students in the 'higher performance' sub-group displayed an average of 61 changes of operation over an average of 23 minutes working time, whereas students in the lower performance sub-group had an average of 72 changes over an average of 26 minutes working time. However, differences in average numbers of changes of operations and time spent in each operation between the two sub-groups were not statistically significant ($p>0.05$) (see Appendices 20 and 21). There were no differences in patterns of performance between the two sub-groups.

5.2.2 Performance of the second-year cohort

5.2.2.1 Time spent and frequency of changes in operations

Performances of the higher performance and lower performance sub-groups were recorded over four consecutive laboratory sessions. The results showed that there were no differences in time spent in each operation or frequency of changes in operations at any time during the period of training, except for week 6. In preparing an occlusal cavity in week 6, students in the lower performance sub-group changed activity to observe (O) their cavity twice as often as students in the higher performance sub-group ($p<0.05$)

(Figure 5.4). However, the time spent in observing the cavity was not significantly different between the two sub-groups in week 6. It is noted however that there was more variation in total time spent within the lower performance sub-group as seen by the higher standard deviation in this sub-group (Table 5.1).



*p<0.05 (Mann-Whiney U tests), data were collected in week 6 of the DCP 2 course.

Figure 5.4 Changes in operation during preparation of an occlusal cavity with GV Black design in higher and lower performance sub-groups

Table 5.1 Comparison of time spent (seconds) in each operation during preparation of an occlusal cavity with GV Black design between a higher performance and a lower performance sub-group

Operations	Time spent (sec)				P value*
	Higher performance group (n=8)		Lower performance group (n=10)		
	Mean (SD)	Median (range)*	Mean (SD)	Median (range)*	
Cutting (C)	647.5 (139.2)	635 (490-840)	560 (154)	500 (400-940)	0.14
Observation (O)	75 (72.1)	90 (20-220)	124 (62.9)	130 (30-220)	0.09
Checking the preparation (I)	91.3 (72)	70 (50-230)	70 (13.5)	65 (10-130)	0.53
Change of instrumentation (X)	28.8 (42.9)	30 (20-130)	45 (62.4)	70 (10-180)	0.96
Total	917.5 (141.2)	940 (690-1170)	869 (234.2)	850 (600-1320)	0.59

*Mann-Whiney U tests, data were collected in week 6 of the DCP 2 course.

5.2.2.2 Pattern of performance

Students in the higher performance sub-group tended to continuously cut their cavity for a longer time compared with students in the lower performance sub-group. However, this result was not statistically significant (p>0.05). Figure 5.5 shows an extreme example of patterns of performance of students from each sub-group. Although one student from the lower performance sub-group (ST259) spent less time than another student from the higher performance sub-group (ST220), ST220 tended to cut the cavity more continually than ST259, ie less ‘observation’ codes were recorded for ST220 than ST259.

ST259 C-------OC----OC----------O---C---O---C----OIC------IC---O--|-C----OIC---O

ST220 C-------------IC----IC---XC------------IXC---------------I--|--O---I---C-------------OC-----I---

ST259 = a student from the lower performance sub-group, ST220 = a student from the higher performance sub-group

Note:
B = insertion of matrix band, C = continuous cutting, I = checking the preparation with probe, S = not cutting and not putting the handpiece down, examining the preparation, or looking around, O = not cutting but using a triplex syringe to clean the cavity, or a mirror to check the preparation, or obtaining and returning an instrument to the tray, X = changing bur/handpiece or hand, | = 10 minute-interval, and - = continuing action for 10 seconds

Figure 5.5 Patterns of operations during an MOD cavity preparation exercise by two students from the second-year cohort

5.3 Motor learning parameters used during the cavity preparation exercise

The results presented in this section were drawn from both third-year and second-year students, to gain different perspectives of motor learning parameters used in completing cavity preparation exercises. To identify the use of those parameters, students in the third-year cohort were asked to report verbally on their performance, using a video recording to specifically prompt them and to assist them to focus on the exercise they had just completed. In contrast, data from the second-year cohort were collected using written critical incident reports, followed by interviews, which included questions related to motor learning parameters students used in completing a cavity preparation. Due to the timing of data collection related to the two phases of this study, (see Chapter 2 section 2.3.7), the following section will firstly report data from the third-year cohort (after completing DCP 2). This will be followed by comparison with the second-year cohort (during their learning phases in DCP 2).

To explore differences in the use of motor learning parameters during various cavity preparation exercises, the current study collected data from higher and lower performance sub-groups in the third-year cohort. Although it was expected that students with a different level of performance would show differences in their use of motor learning parameters (Feil and Gatti, 1993), the results showed no clear differences in the use of motor learning parameters between the sub-groups of the third-year cohort. Likewise, the results of the second-year cohort did not show any difference in the use of motor learning parameters between the two sub-groups. Therefore, the following section will describe common themes, related to motor learning parameters (see details in Chapter 1, section 1.4.3) that emerged from both cohorts. Broader perspectives that emerged from the data collected from the second-year cohort will also be given.

5.3.1 The use of desired outcome (DO) and desired performance (DP) parameters during a cavity preparation exercise

5.3.1.1 Characteristics of desired outcome

Students reported that, before they started cutting their cavity preparation, there were two main issues that they were concerned about: a) an expected outcome referred to as DO and b) the process of how to prepare a cavity referred to as DP. Firstly, students appeared to conceptualise a DO that they wanted to achieve. There were two aspects of conceptualization that could be identified: non-verbal and verbal representation. Most of the students displayed non-verbal representations. These students integrated this representation into all critical procedures of their cavity preparation. They had a visual representation of an expected cavity formulated in either a two-dimensional or three-dimensional form. One student from the third-year cohort described the value of a visual representation in contributing to the completion of their exercise as follows:

You have a 3D kind of image, that's how I would see it because it is real life. The things you see are going to be 3D. As a picture it is obviously not [in 3D] which is harder when you have got an image and you are trying to depict how far you have got to go because the tooth has got different heights and different depths. If I can picture it as a 3D image it helps a lot because I know it is not a 2D, it's not one plane. So if I can keep that it my mind, that it's a 3D image, then it is going to help me out with accuracy of depth. (ST10)

Likewise, students in the second-year cohort also noted two types of representation of a satisfactory outcome. More than half of the students stated that they had a visual representation, and descriptions by three students are provided below:

It's [picture come into mind] usually before that. I'll look on the board and if we have to do an MO or MOD I sit there and I think about it, and okay well then I *need to cut these fissures and this fissure and I'll have in my mind what I want it to look like before I start, but then sometimes you get in there and it doesn't look like what its supposed to be, that's why I think I get frustrated quite a lot, because I have this image before I start and when I start drilling it sometimes doesn't quite fit that picture. It's more three dimensional picture especially with the slot preps - needs to be so…yeah its more three dimensional. (ST718)*

I try to think about the picture before I start doing my cavity preparation. I find this really hard to think about during the process because every time when I start drilling I always think which way I should go to follow the fissure system. So I try to think about the picture all the time so that I actually get the idea what I really need to do. Normally it's [picture] a 2 dimensional picture of the occlusal view and the buccal or lingual view. So it's from the top or from the side. (ST891)

[A satisfactory outcome is] more like a picture because I remember on MyUni they have this, when we did the cavity preparation they actually have the pictures of how to smooth the floor and you can see after they washed it, it was all smooth and you can see it really looks like the table. But my cavity is like going up and down a lot so I was just trying to keep remembering that picture and trying to make it smooth like that. So a picture, I had the picture in my mind because I remember because it was so beautiful, you could see how nice it is. It is something nice that sticks in your mind and I could remember because I still can remember how beautiful it was done, so I was trying to make like that. So all the time when I was… when I had difficulty make the floor smooth I was just trying to find out the areas which are up like going a bit higher up and trying to smooth the floors down. So trying to keep remembering how the picture actually shows everything and it is a flat line. So I tried to put everything down in a flat line. (ST947)

However, some students indicated that they had difficulty in mentally visualising the cavity in three-dimensions. Therefore, they visualised the cavity as a two-dimensional image from different views as noted by one student:

I think it is a multidimensional thing but it is you have got a 3D view of the tooth but you also have several two dimensional views as well. That makes it a lot easier as well because otherwise you are flipping this thing around in your head, it becomes harder whereas if you have got 3D overview of the thing and when you have got these little views, two dimensional views, then you know what each section of the tooth has to look like. (ST9)

In week 5 of the DCP 2 course, one student from the second-year cohort also noted the difficulties they had in managing two and three-dimensional images:

> *Couldn't work out occlusal tooth anatomy well enough to drill it. Had a picture, did a drawing but 2D image translated to 3D tooth in which anatomy not exactly the same anyway was too hard. Had a little breakdown. Asked the tutor to help, she drew the 2D picture onto the occlusal of the tooth, made picturing it easier from then (unfortunately I had already ruined a few teeth). (ST579)*

A few students used verbal representation of the criteria for a desired outcome. Instead of having a representation of DO, several students conceptualised the cavity extension following the fissure system of the tooth. A student from the third-year cohort described how this construct was used during completion of an MOD amalgam cavity on tooth 36:

> *For my cavity, I need the isthmus of the cavity to be at least 2mm. I need the depth to be at least 2mm...have it tapered (ST1)*

Similarly, two students from the second-year cohort explained how verbal representations were used to prepare a cavity:

> *It was more so verbal because that's what we were taught in lecture. I kind of had it step-by-step what I needed to do. We are meant to visualize what the cavity is meant to look like after we cut it, but the way I do it is I kind of just follow the fissures. I don't actually say "okay this is where the cavity is going to be" and like draw it out on the tooth or anything. I just follow the fissures and then widen it accordingly, so I just kind of inch in out to what it should look like, type of thing. (ST496)*

> *No, just step-by-step I did it. I didn't have what it looked like. Sometimes [tutor] would come and change it normally. [Tutor] will come and change it halfway through and then I'll be like "oh okay" so I got a bit confused. In those situations I am like "okay I have no idea" so I have to go step by step and I ask my friends and see if it's the right cavity or not, but apart from that I was able to assess them, using those methods. (ST402)*

5.3.1.2 Sources of desired outcome

The representation of DO was derived from students' experiences in previous exercises, the work of peers, or images in course materials, as noted by three students from the second-year cohort:

> *They come up as pictures. So I have a picture in my mind of what it should look like and then I try and adapt that to what I am doing. So I usually get those pictures by looking at other people's work or sometimes the tutor does a demonstration for us at the beginning of the session, and so I try and remember what theirs looks like and I try and put it on my one. Then there are also pictures in the lecture materials that they give us so then that give me an idea of what I should be doing. (ST156)*
>
> *The thing is I can't remember the whole picture but what I do depending on the area I am working. For example if I am doing the floor I want to remember the floor and then if I am working on the walls I can see how the walls are actually reached and getting connected to the floors. So you can make the corner and the whole wall is smooth, too small to do it I can't remember which specific part I am working on. So just really focus on them and just try to focus on that, just really focus the small areas, specific areas. (ST947)*
>
> *At the start I have an overall picture, but then when you do the different steps like the access cavity then you're just thinking about that a little bit, and then I think at the end you have an overall picture of it. (ST657)*

5.3.1.3 Completeness of visual representation

During cavity preparations, students formulated either a visual representation for each portion of a desired outcome, or the whole final outcome. These pictorial concepts were used continuously throughout the exercise, and were typified by two students who described how the representation was used to guide cutting the tooth as follows:

> *They [pictures] were just still shots from my angle as an operator and I was just hoping to see in virtually what I would see in my mind. I just had the one picture of the completed portion of what I was working on at the time, and I knew that is what I wanted to achieve. [Pictures] Close up, clear, perfect and sort of a goal of what I was hoping to achieve…if you took a digital camera and took a picture*

> *of a perfect the cavity prep [preparation] that is what I had in my mind. I just had to match them up. (ST5)*

> *At the start I have an overall picture, but then when you do the different steps like the access cavity then you're just thinking about that a little bit, and then I think at the end you have an overall picture of it. (ST657)*

5.3.1.4 Awareness of desired performance

The second aspect that concerned students was the procedure for cavity preparation. After they had made a decision about where to access the cavity, a few students intentionally reviewed the whole procedure in their mind and, subsequently, followed the plan in the real situation. They reflected on their past experiences about 'how to do' and/or how the instrument needed to be used and then integrated this into the exercise. Further, a few students seriously focused on selecting types and angulations of burs that they would use as illustrated by one student:

> *I'm just thinking through a certain process of first of all that I want to have support of the handpiece in the right place, but knowing what I want to achieve from putting the bur in there, where exactly does the bur need to be, what type of angles do I need to be using, how do I need to move my hand to get the access that I want. (ST6)*

Two students from the second-year cohort deliberately explained the importance of having procedural knowledge prior to preparing a cavity:

> *Well, I was actually because for the walls, for making the walls and making them tapered I had to make sure that the angulation of the bur is correct. So I kept, that is what you have to, is make sure the angulation, actually I was actually more thinking about the bur that I was using. Because the bur especially the pearl ones become actually having little bit of angle the bur is like that. So just like pearl shape. So they have this angle so you can, you don't have to worry too much about the angle of the whole bur but you can actually make sure the tip of the bur is angled in a way that can actually make it smooth, a smooth wall which is tapered as well. So you don't have too much of moving the bur around. That was trying to use, make the job easier by using the good bur. (ST947)*

For the cavity, it is good to know because we're not going after caries yet, we are just doing minimal intervention. So you want to have in your mind where you are going to go first. Where you are going to insert the bur first of all to open up the cavity. And then you want to think about how big you want to make it, and by that you want to make it a small possible so you work from small to larger, I guess if that makes sense. Then I always think of the shapes, following the fissures or the shape of the slot or… and then the depth and you visualise with the bur's height and then take it out, measure it, take it out, measure it. Just from experience, minimal experience but from that just going… when you know what you are supposed to do, you can do it a lot faster. Instead of when you are questioning yourself and you don't know how deep you have to make it or where you want to extend it. You keep doing double work because you extend it and then you have to round it, and then you do that. So it builds up, where if you know what you want to do, you just do it in one go. So that makes it just a lot more easier for us, or if you just do it with the high speed and you know where you want to go. So then you can be more comfortable in doing that, instead of using the slow speed and don't really know where you going. (ST591)

Apart from the previous two students, few students described details about the visualisation of bur movement or bur angulations prior to cutting a particular portion of a cavity. One student from the third-year cohort imagined the desired bur angulations in a two-dimensional form, either with or without superimposing the diagram of the expected outcome:

It's just like something like imagination in my mind, picture in my mind of how the angle should be and then I will just taper it. I mean I just angle the bur according the angle that I want. It is more like two dimensional I think. (ST11)

One student from the second-year cohort also described how to determine the angle of the bur before start cutting:

I would think about it and especially during the initial access and everything, I think this has to be parallel and I adjust it before I actually start drilling anything. There are times where I would start drilling and before I'd start drilling I would place it over where I was going to drill and do the motion. Then I would do it. Same with the prox-boxes, I'd drill down initially and then angle it a bit and angle it a bit the other way. (ST435)

5.3.1.5 Relationship between DO and DP

Some students explained that it was difficult to develop an image for the entire exercise. Firstly, the mental image disappeared occasionally when they focused on the position of the bur, particularly how far the bur went through the tooth. Secondly, for a student who used a verbal approach based on laboratory instruction, the imagery was extremely abstract to manipulate:

> *Once you have actually made the access you lose it a little bit, you lose the image because you are focusing so much on the bur and where you are positioning the bur and how far you are going. You subconsciously are feeling where you are going but you are also thinking about am I going the right depth? So you might lose a bit of that imagery that you are trying to sort of trade. (ST10)*

> *I try to think about the picture before I start doing my cavity preparation. I find this really hard to think about during the process because every time when I start drilling I always think which way I should go to follow the fissure system. So I try to think about the picture all the time so that I actually get the idea what I really need to do. (ST891)*

Students used DO and DP in different periods of the operation. For instance, prior to making initial access or in a critical aspect of a preparation, students initially considered the angle of the bur and, then, during cutting the cavity, they focused on achieving a satisfactory outcome. According to one student:

> *When I first enter the initial cut, I think about it and then after that when I just think that the cavity, follow the fissures, I don’t really think about that much until they’re all done and then I'm always thinking I need a taper them, but I think at the very beginning it was very much oh I need to taper them, I have to keep remembering this, and now I think it’s starting to come on more naturally, because I found that with my feedback its becoming less apparent that I need to taper them, because initially I'd think about it and I'd miss certain areas and so my tutor would tell me "Oh you have to go back and do this bit, taper it more, angle it more" but now it’s more natural because I've just had it hammered into me, so now it's subconscious thing to taper them, so there is less feedback of me needing to taper them because, most of them are already tapered. But I find that with the maxillary teeth I do think about the*

angulation quite a lot, just because its quite awkward still, and just with the indirect vision, I always have to think about, "okay which am I going mesial or distal or... so I'm always thinking about the movement of the bur, because I'm still trying to get used to indirect vision, so it's more of an active process". (ST718)

5.3.2 The use of knowledge of results (KR) and knowledge of performance (KP)

In general, students aimed to match their cavities with the DO that they were trying to achieve. During preparation of their cavity, they would compare their actual cavity with the DO in their mind. Initially, self-evaluation processes by students in relation to KR will be presented, followed by knowledge related to error information, ie comparison of their actual performance and DP.

5.3.2.1 Self-evaluation processes in relation to outcomes

Most of the students evaluated their cavities continually and they completed self-assessment before they continued on to the next phase of cutting. When they were cutting particular regions of their cavity, after each bur movement, they assessed which part of the cavity needed to be improved and where the next movement was required.

Of course throughout the time, well first of all, when I am actually drilling it, it is really wet so I can see the depth, I can see the width but I can't really evaluate how smooth the walls are or how flat the floor is during that time. So normally when I dry the tooth it is that time that I actually evaluate it and continue working, so it's pretty much a continuous process of evaluation throughout the entire time. I just drill a bit, then stop, dry it, take a look, then move on and see which part needs to be cut some more and which part I have to stop cutting on. (ST2)

At first time I cut once, then I would check it again and then I would check and them do again a little bit, and then check it again little bit, drill again. But as I get more experience then I'll cut over half of it and then think, "Oh okay I only need to cut a little bit, then once or twice I check with that". It's less time I used the periodontal probe. (ST233)

I don't know. I don't exactly think about when I need to stop. For example if I am doing an MOD and I'm starting by drilling the access cavity into the D, I would *drill that and stop, look at it, just to check that first bit is okay. It's very frequent, just every tiny bit of drilling I just make sure that I haven't gone too much or in the wrong spot or anything like that and before I'll get the next bur to start going along the fissures or something, that I'll always check that. When I remove the thin enamel a lot of people are choosing the hatchet option. I'm just, I don't know why, but one of the tutors just recommended using a slow speed flat fissure and so I am just used to that so obviously I don't just keep drilling off the enamel, I just do a tiny bit, tiny bit, have a look at how thin it is left and how much left there is room, keep drilling a tiny bit, look. So it's just very intermittent, very frequent. (ST529)*

Most students in the lower performance sub-group evaluated their outcome more frequently than students in the higher performance sub-group. The students from both sub-groups used similar strategies to evaluate their outcomes. They tended to stop cutting to check their outcome - firstly, when they thought their outcome was close to what they wanted, and secondly, when they felt they had done something incorrectly, resulting in an unexpected outcome, or when they were cutting a critical part of the cavity such as a proximal box.

Students tended to assess their cavity using visual estimation as feedback when they could see the cavity clearly. They used this estimation for checking several aspects of the cavity, eg width, tapering of walls and smoothness. Occasionally, when they could not see properly, they judged these two aspects by tactile feel using a periodontal probe. In the middle period of the preparation, instruments were often used to obtain measurements. For instance, they preferred to use a periodontal probe to check the angle of the walls and depth in proximal boxes because they could not see that portion directly. Toward the end of the procedure, they tended to measure the cavity frequently in order to check whether their actual outcomes matched with the criteria in their mind. For example, one student from the higher performance sub-group explained their thinking processes when preparing their cavity:

> *This is where I think about tapering of the walls for retention. I prefer to use angulations than not checking holes and things like that. So if you want to hear about my thought processes, I picture like a zooming in on the tooth and in my mind turning it into a going inside the cavity prep to picture how steep it is from the inside and trying to match my vision to reality. (ST5)*

5.3.2.2 Evaluation of bur angulations by comparison with DP

While students were likely to evaluate an actual outcome consciously, they often evaluated bur angulations subconsciously. Most students in both cohorts indicated that they did not have to think about bur angulations during cutting (performance) because their focus was on the actual outcome. Comments by two students were as follows:

> *Not consciously. You look at the cavity and you know what you want to change about it but I wasn't literally thinking my bur's at this angle. Basically, I was using the bur subconsciously to do what I wanted it to do. So I wasn't specifically thinking about what angle is the bur at this stage. (ST7)*

> *I don't know, it's sort of sub-conscious, like I'm about to start it doing something then I check the angulation. Usually I sometimes forget to evaluate it halfway through when I'm cutting, because I'm halfway through what I'm doing, so I'm more focused on keeping the bur going and the correct direction and angulation, but I guess what I'm saying is I assume that I check the angulation so I'm like okay the angulation is correct, I don't need to think about it anymore. So basically at the beginning of each step or each time I put the bur down, I check. (ST690)*

They tended to assess bur angulations when they were dealing with critical aspects of cavity preparation, such as proximal box preparation, for which the angulation of the wall is an important criterion. Furthermore, as noted by two students, they would carefully check the angle after they found a mistake from their previous bur movements:

> *All the time. Just always keep an eye on the bur, because the bur determines the cavity prep. If the bur angle is wrong then you know you are really going to have really bad shaped cavity prep. So the bur angle must always be at a correct angle for the rest of the cavity prep. (ST1)*

> *I initially thought I know I have to access it perpendicular and then once I had done the outline, then I will start converging the walls. So I was thinking about that [bur angulations] but I think also at the time, I think I had a problem with depth control. I think I might have been watching the depth of the bur first as a priority to improve that. Then later on in later lab stages, I got the hang of working with both depth and angles. I think at that point in time I knew about the angle, like how to access it straight then converge it, but then I think I may have been concentrating on depth as well as my perception of the angle was wrong. (ST403)*

Students tended to check and correct bur angulations by sensory feedback. Most students performed cutting with little awareness of bur angulations. They evaluated the proper angulations using tactile feel and placed emphasis more on evaluating the outcome. They claimed that this sense was developed through their experience during practice. For example, if they were sure about their finger control movements, they tended to evaluate the cavity (outcome) rather than evaluating bur angulations (performance). One student mentioned that having a representation of the final product in his/her mind would be followed by steps that were required without conscious thought:

> *So having the angle of the bur at the back of your mind, it is not a conscious effort of saying "I need to get the angle correct", but more of the fact that you need to get the size correct and your angle of the bur just follows through. You will naturally come at the right angle. I guess this is because you have at the back of your mind all of the time, you want a nice smooth finish, a nice cut cavity, so it will always be there and then your main focus is your outcome. When I have a focus on the outcome where are appropriate size and appropriate depth, then the how just seems to manage itself that I will get my bur at the correct angle. Yeah, I guess that it is more the fact that once you have a focus of what you want right, every time to flow through. The bur, everything just flows into place… (ST1)*

Overall, students tended to focus on checking for KR rather than KP, as this formed part of the assessment of their performance in the course. They reported that management of bur angulations became automatic by practising:

> *because the bur angulation is something that just comes to you, you can just, you know how to do it. It is something that you have learn, people tell you here you have to angle it this way. Something like this is basic commonsense that you need to, it comes to you like breathing you don't learn how to breathe. Bur angulation is just something you just know how to do it. Because if you want to taper a wall you have angle the bur and you just try and try, trial and error and just try this and just try that way so you actually make it right. But for the satisfactory you have to know what shape you want so you can actually achieve that otherwise you just doing it doesn't get you there.*

5.3.2.3 Use of tactile feedback to inform knowledge of performance

Students from the second-year cohort reported how they evaluated DP while they were cutting using tactile feedback. This feedback was developed through a method of trial and error and this helped students to perceive the amount of pressure they needed to apply to a bur during cutting:

> *I thinks it's a matter of just getting used to, because initially I didn't really know how much pressure or how far down I should put the bur, how I should angle it, how fast I should run it and now I think with trial and error, I'm getting more used to applying a certain pressure*. (ST718)

> *well I mean I already had a pretty good feel just from like the feedback you get from the bur of what sort of density the tissue is that you're touching, or the plastic in this case. But just to make sure you don't go into pulp or dentine, or too much dentine which is softer as well, that's why I had to keep on washing it and drying it and checking it and just making sure I'd used lighter pressure all the time I guess but especially as you saw that you were getting closer to getting rid of all the caries. So that's just the only way that I could check where I was at, really. (ST220)*

5.3.2.4 Sources of comparison

There were several sources of information students used when reviewing their outcome, eg course materials, previous work, diagrams in their laboratory manual and peer/tutor feedback. Details of each source are provided below.

5.3.2.4.1 Course materials and previous work

In order to evaluate whether an actual outcome was satisfactory, students initially self-evaluated their outcome by comparing the actual outcome with various sources of information, eg course materials and previous work. Eight students from the second-year cohort noted that they self-assessed their cavity preparation against criteria provided in lectures and their laboratory manual. Two of the students commented as follows:

> *Well we had the checklist, well I mean it's not a checklist that is what they said in the lecture. Good cavity preparation qualifies the walls to be smooth and a little bit tapered, the corners should be a bit round and the floor has to be smooth. So after doing this I was making sure that cavity depth, the wall is nice and smooth and the corners are rounded, the floor is flat so these are the things that I kept trying to have work on because sometimes you get wonky floors and you keep having to have it probed to go on the floors if it is all smooth especially because the tutors usually pick on that. (ST947)*

> *Satisfactory in terms of like for example we have always been doing this I think when we start using Frasaco^{TM} teeth, the plastic teeth, you always go for 2mm deep in the occlusal part and then 4mm at the proximal boxes. That's the standard that I use for doing the amalgam prep. I think it's through the exercises that the teachers gave us to do in the beginning. They asked us to go for 2mm on the occlusal when we started with occlusal prep that has occlusal cavities and then after that move onto proximal boxes. They say that we can go to 4mm so I just follow that. (ST512)*

Alternatively, some students stated that they compared their current work with a visual representation of previous work completed in an earlier session. However, for exercises that consisted of similar components, eg MOD cavity preparations, they were more likely to evaluate the quality of a proximal box with one completed previously. Students were likely to evaluate the outcome by comparing it to what they had experienced previously, either the positive or negative aspects. For example, one student in the higher performance sub-group compared a current outcome with a satisfactorily completed task that had been performed in the past as follows:

> *Just memory, by memory. I just imagine what I recall from last week and compare it to the current week. If last week's one is better then that means this week I have not been doing so well. Just direct comparison. (ST954)*

Likewise, one student in the third-year cohort reported that:

> *It matches what I have in my head, and maybe there's a few variations of what's good in my head and if it matches. If it looks the same in my head as it does in my model then I am happy with that. That's satisfactory. (ST5)*

Alternatively, some students were concerned about things that they had done incorrectly before or even what a tutor had said was wrong. They aimed to avoid similar mistakes with a focus on improving the outcome. Two students described how this comparison was used to evaluate an outcome:

> *If I was cutting the cavity and then I would go by in past sessions, make sure I didn't do the same things wrong, so just simple things like using the right bur and making sure it was the right one for the cavity. (ST472)*
>
> *It's more I think about the mistakes I did before. Not just the mistakes but what caused the mistakes, because I would have discussed that with my tutor. So if it got deeper because I kept trying to fix it but that was because I kept applying pressure so there was uneven height. One of my tutors said less is more, so you keep doing it, and you apply feather-like pressure and everything like that and then you just keep checking. It wasn't too bad if I did the exact same exercise or one very similar the next week or immediately after, because I had actually learnt slightly from my mistakes before. I mean they weren't perfect, but I tended not to make the same mistakes again. If I did it too deep it wasn't because of the amount of pressure I applied. It might have been a bit because of bur angulations or something else. (ST435)*

Whichever method students used to evaluate their work, they checked each characteristic of the cavity in their mind as a check-list in order to identify what needed to be improved. The check-list included general characteristics of cavity preparations based on both GV Black and minimal intervention concepts. For instance, with a plastic tooth without simulated caries, students were aware of the requirement for an appropriate occlusal outline, smooth walls, flat floor and depth of the cavity needed to achieve a satisfactory outcome. Some of them were also concerned about the possible clinical implication of the cavity preparation, eg a critical area of a tooth's anatomy in relation to the pulp cavity. When using plastic teeth with simulated caries, students from the second-year cohort also indicated that a satisfactory outcome was related to the completeness of caries removal. Students used a range of measurement tools including an explorer, periodontal probe, and mouth mirror for assessing different dimensions of a cavity:

> *With this task when I used the periodontal probe I also checked the depth of the cavity. When I first did it I wasn't really aware of about measuring the depth of your cavities, but as I went through as I learnt more as the weeks passed, I learnt to check how deep I was making the cavity to make sure I wasn't hitting the pulp so I used the periodontal probe to check that I was making smooth walls and that the cavity was the right depth. I also used my explorer to check the smoothness of the walls and the floor which I didn't use earlier. (ST156)*

> *I evaluate it based on depth, so how deep my cavity was, whether or not I would have hit the pulp, whether the angles around it, the floors are flat, if there was that 90 degrees angle for the convergence of the walls. And if there was adequate depth from the proximal box to the occlusal floor when doing a slot prep, and just how bur angulation and flaring of my prox boxes was all right. I wanted a 2mm cavity and 3mm prox boxes. I judged it using an explorer and I used the explorer to judge how smooth my floors were, just by feeling it, tactile [sense] and I also judged by how I used the explore, not the explorer sorry, the periodontal probe to judge the angle of my wall slot. I used my mirrors as well just to see, because it is very hard to look at the distal prox box especially if there is an adjacent tooth so I use my mirrors and yeah just the periodontal probe. (ST259)*

> *Well I mean I already had a pretty good feel just from like the feedback you get from the bur of what sort of density the tissue is that you're touching, or the plastic in this case. But just to make sure you don't go into pulp or dentine, or too much dentine which is softer as well, that's why I had to keep on washing it and drying it and checking it and just making sure I'd used lighter pressure all the time I guess but especially as you saw that you were getting closer to getting rid of all the caries. So that's just the only way that I could check where I was at, really. (ST220)*

> *Well looking at is there a consistent depth, is it wide enough for what they're asking for, so if its large, or if its amalgam, is the isthmus are too narrow or anything like that. Are the walls and the floors smooth, is there any unsupported enamel. Then when you go to the prox-boxes, are they consistent,*

is there retention and everything like that. Just the things we are meant to be doing when we evaluate. (ST435)

However, they still had problems with depth perception while cutting a cavity. To solve this problem, some students estimated the depth of the cavity using the length of a bur. According to one student:

Well the first session, we started drilling into the inserts. They asked us to drill certain depths into the insert, and some of them were 2 – 3mms and so forth. I thought to myself it is a little bit hard to gauge how deep you are drilling because you can't look right into the cavity and see what you are drilling. So I thought "Oh well what is the length of the bur, what is the length of the cutting of the bur" and that was 4mm, I measured it with my probe. Then I thought well "if that is 4mm and I want to drill 2mm" I can roughly say "oh if I just drill to about half of the length of the bur it will be roughly 2mm" and if I just keep at that level, I can make sure I have a 2mm depth across the whole line that I'm filling and I can ensure and make it easier for me to get a smoother floor, cavity floor. That is how I figured it out. (ST210)

5.3.2.4.2 Diagrams in the laboratory manual

As well as comparing their outcomes by referring to course documents or their previous outcomes, students would check the quality of their current outcome by comparing their work with a diagram of an expected outcome in their laboratory manual. This provided a valid example of what was expected. According to two students:

In our lab books they have pictures of the steps and what they look like when they are finished and stuff like that. So I always check back to see if mine has any resemblance to theirs. Because I know theirs looks cleaner and defined than mine all the time so it is just a good way to check off on how I'm doing. (ST820)

I just looked at the diagrams in the lab manuals as I said before, and if it doesn't look like the same shape then, I generally rate it as pretty bad, depending on how out of whack or how out of shape it is. If it is really badly out of shape I rate that really poor, if it is close enough I reckon that is pretty good, but in relation to the first couple of weeks it was like I was before, I was just comparing the shapes, the shape of my drilling to the shape of what was in the lab book. (ST210)

Students described how useful it was to have an example of what a good cavity preparation should look like. Several students noted that working with plastic teeth without caries made it difficult to estimate how much tooth structure needed to be removed and to be consistent with the concept of minimal intervention. According to four students:

> *For me it's more an image because I know people learn in different ways. For me It's more… sometimes I have trouble articulating what I want it to look like because I don't know verbally what it should like look, but I can draw it or…that's why sometimes it's quite useful - my tutor will draw how I need to improve it and I find that useful. Instead of him just telling me I find it easier if he draws it or actually shows me. If it's verbalised I don't really know exactly how it's supposed to look, so for me it's easier if I have a mental picture or actually like a drawn picture of what it should be. (ST718)*

> *Because my tutor showed me other people's stuff, like how smooth a cavity should be and he did one as an example on another tooth, like one was smooth and one was not smooth to sort of compare. Like when you compare you actually you know which one is good and which one is bad, and this is where you work from. Actually you can compare, if there is nothing to compare with, it is pretty hard to imagine that how a good one is, because obviously this is a good one and how to follow what a good one should be. (ST194)*

> *I wish we had an example of how the cavities are suppose to look like (a drawing/picture) that would help a lot (setting a goal for what it is suppose to look like). (ST243)*

> *Sometimes in other sessions I have drawn a few pictures. I find that helpful, and the tutor has actually done that which really helps, on just those little sheets of paper we get on our trays. I don't know how I did it in the end. I suppose I just thought about it and plunged into it. Probably the wrong approach. (ST657)*

However, one student reflected that the expected outcome in the manual was too idealistic, and that it was not easy to achieve this standard at the beginner stage. Therefore, the student preferred to evaluate their own work with peers rather than with a perceived perfect model:

I would be able to describe it verbally but I have got the images, which is easier to follow. I think ideally it would be good to compare it and contrast it to pictures in a book but because we have only been doing it for just over a month, nearly two months I think we have got to stay relative to just our peers. As long as we are all around the same level, but there is not many of us that would be able to achieve the perfect cavity prep at this stage. (ST529)

Alternatively, two students noted that information about how to complete the cavity preparation was required to assist them in achieving the outcomes displayed in the models:

Well the beginning of the semester I had no idea. Because pictures are all well and good, but we were never shown how to do it, so I was very much lost and tried to ask at each step what to do, so yeah it is different. I'm more confident in what I'm doing because I actually know, now that some how managed to learn. I know what to do now, so it is different because I have more confidence in when I'm doing it. (ST690)

Videos that we have online which we can watch of the different cavity preps. They help a lot, although sometimes because you want to try grab what you see there. It is like a blank canvass so you don't really know what you are doing. You read about it and you know – let's say you are doing an MOD. You know the theory behind it but to actually get to the tooth and start doing it, you don't really know every step of the way what you are going encounter, so those videos help, but they are all like the perfect scenarios. So when you actually do it, you see the obstacles where you can go through and I found things that helped me a lot was when the teacher would draw me a picture. Like what you are suppose to have it look like, and not what it… I mean those are the things which you encounter only by doing it, by trial and error, because the videos that we have online, as I said are like the perfect scenarios where when we do it, it is little things which you didn't even notice when you looked at the video because it is the first time you see it. So you don't notice every little detail. For example rounding the corners and not having them sharp. You don't even think about it until you do it, and then your tutors will draw for you for, it is more like this or more going out like a "V" shape instead of like parallel two walls. You just do that by… and I am very visual so if you know how it is supposed to look like, and transfer that to your head and do that. It is trial and error. (ST591)

5.3.2.4.3 Peer and tutor feedback

In addition to internal sources of feedback from routine self-evaluation, comparison of a current outcome with peers and asking for feedback from a tutor were also perceived to be helpful methods for evaluation. Many students noted that they tended to seek feedback from their peers to affirm that they were creating a satisfactory outcome. They would get ideas and feedback about their work from other friends in their group. As the students did not know exactly 'what is expected' for a particular exercise, they wanted to make sure that they were on the same track as their friends. In addition, they would ask their friends to criticise their work or to show them how to solve similar problems. According to three students:

> *Also we compare each other's work after lab when we are writing up our self assessments we usually just hand around your mandibular arch or the arch you have been working on to the other students and you're like "oh wow" you can tell when someone has done really well because you can see that it's all smooth walls and flat cavity floors. (ST156)*

> *But then if the tutor was busy with someone else, I would ask the person next to me just to have a look their cavity and make sure mine was similar size, not too big not too small, see if we were on the same track and then when the tutor was free I would just ask them to check. (ST472)*

> *As well as in the lab sessions there is a couple of the girls that sit next to me who in my opinion are quite good at what they do and they are very confident with their skills and their knowledge and I think that serves as a good backboard. Just as I have… each group has one tutor and the tutor is always busy and the tutor is got many other things to look at so if I have got a quick question rather than waiting ten minutes or however long, it's easier to just tap the shoulder of the friend next to me and just ask "what do you think of this" and then we will discuss together what is good and what's bad and what still needs to be done. I probably wouldn't call the tutor until I think that I have arrived at the end product. (ST529)*

In addition to obtaining a second opinion from peers, students tended to ask their tutor frequently for feedback during an exercise particularly in the first few weeks of course. More than half of students acknowledged that their tutors' feedback was a useful learning guide for improving their skills. Although they initially evaluated their work based on criteria and procedures discussed previously, they still depended on their tutor's judgement about whether their outcome was satisfactory:

> *Well in week 5 I still really wasn't sure what we were supposed to be doing because we were getting mixed messages from everyone, saying "do it this way, do it this way, do it this way" and then by the time it got week 10 it just sort of went "No, I'll do it my way". You know what one tutor wants and you know what anther tutor wants so you can adjust between the two, just more of a feel for the tutors I guess and what they are looking for. (ST827)*

> *Oh yeah, I actually asked my tutor to see it first, and if he say it is not good and he let me see and feel that it is not and I would do it again and if the floor is really not even and I think that is not good, it is not satisfactory I would probably have to even it out again. (ST194)*

> *I would evaluate it after I would cut initially. So I would get in there with my high speed, cut the initial cavity, evaluate it, figure our whether or not I still need to use the high speed or whether I could switch to a low speed and start smoothing up the walls or smoothing the floors. If not I would keep going with the high speed and cut a bit more. Then usually after I have cut my initial cavity I would get my tutor to check it. I would get my tutor to evaluate it and then I would ask my tutor what else needs to be worked on and I basically do whatever my tutor told me to do. (ST259)*

Feedback received from tutors for each exercise in the first few weeks of the course seemed to be essential in helping students to be able to identify errors in their outcome. This resulted in constructing their views of the expected outcomes. According to one student:

> *At that time I didn't have very clear idea of what the fissure system is. I know I can see the fissures but I didn't know how to follow the fissures so the cavity came out quite irregularly shaped. I didn't actually follow the fissures but now, after I also asked my colleagues to tell me what the cavities should be like and I think after a few sessions, I gradually got to know what the cavities should be like and instead of making the cavities very big I try to make it as small as I can. (ST891)*

5.4 Summary

To investigate additional aspects of individual differences in learning skills needed for operative dentistry, observational and qualitative studies were conducted with sub-groups of students in Phase I and II of the current study. There was no strong evidence to support differences in procedures used during completion of cavity preparation exercises by sub-groups of students selected from each end of the performance range. Differences in time spent and frequency of changes in action during the exercise between two-sub-groups (in the second-year cohort) were only found in week 6 of the DCP 2 course (see section 5.2.2). No differences were found in the third-year cohort. Several issues need to be considered related to sample sizes and the criteria used in selecting sub-groups of students for the qualitative study. These issues will be discussed in Chapter 7.

Students in both cohorts used motor learning parameters in a similar manner regardless of differences in their stage of learning. They deliberately described the use of desired outcome (DO) and knowledge of results (KR) parameters during cavity preparation and they placed their focus of attention on achieving a satisfactory outcome rather than on how they might achieve it, ie they did not tend to focus on parameters related to desired performance (DP) and/or knowledge of performance (KP). Several aspects related to DO were noted such as sources of information about DO that students developed through practising exercises. The relationship between motor learning parameters and other factors related to the development of those parameters is summarised in Figure 5.6.

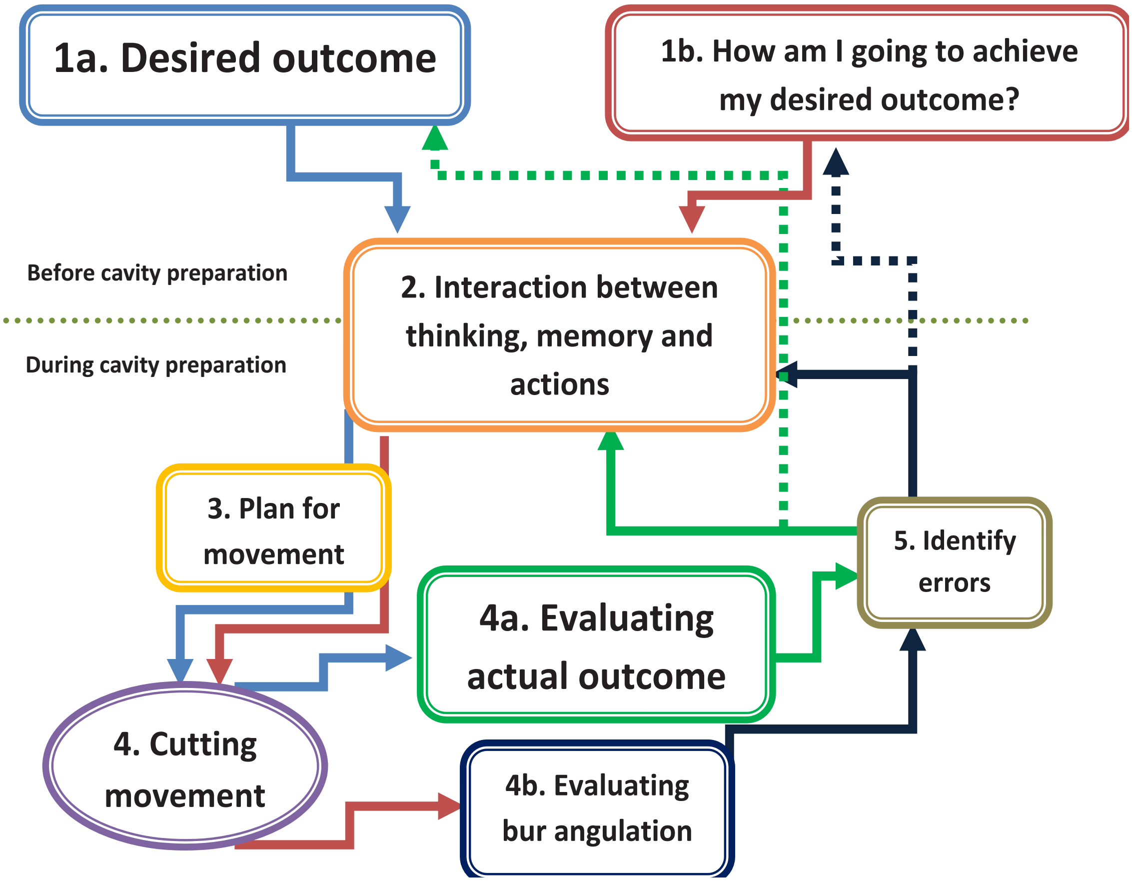


Figure 5.6 Diagrammatic representation of motor learning parameters used by dental students to complete a cavity preparation exercise

Figure 5.6 illustrates that before making initial access in a tooth, most students tended to conceptualise their desired outcome – DO (1a) either in a verbal or non-verbal form. The characteristics of DO and completeness of visual presentation varied between individuals. A few students were aware of ‘how they were going to achieve’ their DO (1b), which is a DP parameter. Theoretically, information about DO and DP would be manipulated and modified using recall schema (2) related to the movement required to complete the task (see Chapter 1, section 1.4.3), resulting a plan for movement (3). The students would then cut the cavity following the plan (4). During completion of the cavity preparation exercise, most students tended to focus on evaluating their cavity outcome

(KR)-(4a) rather than evaluating their processes, eg the angulations of the bur (KP)-(4b). Theoretically, recognition schema which are responsible for identifying discrepancies between DO and actual outcome (5) as well as DP and actual performance, would play an important role in helping students adjust the next movement to achieve the desired outcome.

According to the results reported in Chapters 4 and 5, it seems that factors related to individual differences, eg ability, motivation, and use of motor learning parameters, cannot solely explain differences in performance. As the practice environment is a key factor in promoting effective learning of skills, the next chapter will present detailed information about students' perceptions of effective and ineffective learning experiences during DCP 2.

Chapter 6 - Perceptions and experiences of learning during the DCP2 course

In addition to individual differences in motivation and ability that may influence performance, there is evidence that the practice environment also plays an important role in skill acquisition (see Chapter 1, section 1.4.4). The practice environment, including practice schedule and variability of exercises, has been investigated previously in surgery (Brydges et al., 2007) and sport sciences (Masters et al., 2008) and the findings show that performance variability is evident due to these aspects. However, little is known about students' perceptions of the design of their practice environment and how this supports their learning. Therefore, the current study investigated this aspect in second-year students participating in an operative technique course (DCP 2).

This chapter presents characteristics of the learning activities that students perceived to be effective and ineffective for their learning. Critical incident reports and follow-up interviews were used in four consecutive laboratory sessions (see Chapter 2, section 2.3.7). These sessions were chosen according to the complexity of the exercises and cavity preparation skills that were needed to complete tooth 36 (MOD). This included two sessions in semester 1, ie week 5 (occlusal cavity preparation) and week 10 (slot with occlusal cavity preparations), and two sessions in semester 2, ie week 8 (slot with occlusal cavity preparation) and week 11 (the cavity preparation exercise). Several themes were derived from the reports and interviews, ie roles of tutors in enhancing skill learning, perception about the quality of cavity preparations and restorations, roles of peers in self-evaluation, and experiences with operative technical problems. These themes are presented in sequence, according to the numbers of students who reported issues relating to them.

6.1 Roles of tutors in enhancing skill learning

6.1.1 Arranging group discussion to clarify processes and outcomes

Students noted that having their tutor set up discussions in their group helped to clarify 'what to do' in the subsequent exercise. In the initial few weeks of the DCP 2 course, students were confused about bur selections and use of dental materials. Nine students noted that it was helpful having a discussion with their tutor at the beginning of laboratory sessions about the expected outcomes and how to achieve them. This activity was perceived by students to be needed to clarify the theoretical knowledge applied to the practical exercise. For instance, ST517 cited an experience in week 4 of the course where the exercise involved sealant application. Initially, the student was not confident about doing the exercise but felt more confident after the tutor had held a tutorial discussion with the group prior to commencing the activity:

> *[My] tutor had a tutorial about the different restorative materials before we started our practical work. Knowledge of GIC [glass ionomer cement] and CR [composite resin] revised with the linking of product names available in the lab. Steps of different sealant restoration types were listed. I felt more confident once the steps were linked out. (ST517)*

This experience was in contrast to that of ST914 who noted their experience in week 5 when the group was assigned to another tutor. In that session, there was no discussion with the tutor at the beginning of the session:

> *I just guessed what I should do and I did it badly with the wrong instrument. My main problem is I don't know what the end product should look like and what tools I can use to achieve that. I kept being told the cavity wasn't good*

> *enough. I felt very frustrated after the session because [I] don't know where to get information. (ST914)*

Consistent with ST914's experience, tutors were not always perceived to enhance skill learning during the group discussion. ST238 also had a negative experience with their tutor in week 3, which was the first exercise they had done involving a composite resin restoration. The tutor asked questions of the group regarding the properties of glass ionomer cement and composite resin. The student was confused about how to handle composite resin so the student asked the tutor about it:

> *[I] asked the tutor what unfilled resin was for. [My] Tutor laughed [at me] and call [another tutor's name], so that I could ask [the same question about unfilled resin] again and [I was told that I did] not do pre-reading. [After that my] tutor explained [what] unfilled resin [is]. [I felt] embarrassed and frustrated; seemed to encourage 'don't ask questions' mentality. (ST238)*

6.1.2 Providing feedback

Almost half of the students identified experiences related to feedback received from their tutor. Positive feedback with practical tips to solve problems during activities was noted to provide effective learning experiences. For instance, students who made mistakes and/or repeated errors in an exercise, were potentially motivated to improve their performance by positive feedback which focused on the cause of the errors and techniques, or 'tips', to fix the errors:

> *[My tutor] drew a picture and this visual example really helped me improve my future slot preparations. She reviewed concept of what a slot preparation is, in what scenarios a slot preparation is required. This experience has remained in my mind because I made an improvement and I now be able to know what I need to do in such a situation. (ST591)*

> *The task involved drilling artificial caries from an acrylic maxillary arch. Initially my cavities had rough pulpal floors and walls, but with the tutor's tips for improvement during the session and continued acknowledgement of*

> *an improvement – the cavities ultimately had a better shape and were smoother. (ST194)*

> *Bur angulation: by having tutor's advice and adjusting finger rests and instrument grip, smooth and rounded corner could be made for my second cavity, which showed effective learning results. (ST282)*

> *It was a bit annoying that the restoration on buccal surface was bulbous [so during the activity] I asked for advice on overfill. After [the experience], I felt that I had learnt a valuable technique. (ST369)*

Although 'what to do' information is provided in a laboratory manual, students sometimes might not be able to apply this knowledge to practice. They may know theoretically 'what to do' based on the laboratory manual but, in the practical setting, unexpected events happen and this information may not be covered in the manual. When students had difficulty completing an exercise, practical tips provided by their tutor were found to be very helpful. The common problems that students reported included application of matrix bands, manipulation of dental materials, and producing a round angle cavity and/or flat wall as part of cavity design. For example, ST794 made the following comment about a first restorative exercise involving the proximal portion of a tooth which required extensive polishing:

> *[My] tutor instructed [me] to be careful with placement of composite resin. Make accurate to reduce need to polish and also to provide better anatomy. [I] used this tip to advantage on second restoration - less time spent polishing back. It was a tip on technique that can be applied for all restorations. (ST794)*

In addition, having a discussion about satisfactory and unsatisfactory aspects of an outcome with the tutor was considered to be helpful. For example:

> *As the tutor pointed out/discussed issues I was going to have with filling the cavity, he educated me more on minor differences of a prep that can affect the end quality or difficulty of the restoration could modify preps the next time. (ST220)*

A few students reported ineffective learning experiences in relation to feedback received from their tutor. These included non-specific feedback and feedback that focused on mistakes but not on how to improve. Firstly, students preferred specific feedback and they expected not only information about errors in their outcome but also discussion of strategies to avoid the same error in subsequent exercises. For instance, in week 5 of the course, ST603 was struggling to prepare a flat floor for an occlusal cavity for an amalgam restoration on a plastic typodont tooth. The student asked for feedback from the tutor but the tutor only pointed out the error and did not give strategies for improvement. The student felt confident with their knowledge before doing the task but then later in that session felt frustrated:

> *I found this session unpleasant because [I was] frustrated at [my] tutor as [my tutor] was not answering my questions or offering strategies for improvement. [I] felt [my tutor] was not appreciating improvement. (ST603)*

Likewise, when ST404 chose to prepare an MOD cavity on tooth 16 for an amalgam restoration, the cavity preparation was satisfactory but the student encountered some difficulties with their restoration. The tutor suggested using an image to help with the occlusal anatomy but the student felt that was not useful:

> *I attempted the restoration a few times with no improvement. [I felt] I knew the anatomy but struggled to put it on the tooth. I became frustrated with my own performance and also my tutor who I felt was not giving relevant advice. (ST404)*

Other ineffective learning experiences occurred when tutors focused on mistakes rather than on how a student could improve. For example, in the last session of the course, students were allowed to do any exercise they thought needed to be improved. ST820 wanted to do restorations on unfilled teeth that had not been finished in previous sessions, as well as a couple of MOD cavities. However, their tutor did not agree with the plan. The student completed three MOD cavities and one amalgam restoration but the tutor pointed out errors in the outcomes and told the student to improve:

> *I was quite worn out and so wanted to stop for the day but the tutor was unhappy and provided no positive feedback. The whole session completely diminished my self-confidence in ability to do dentistry. I didn't even have to judge [how I was going during the cavity preparation], my tutor was judgemental enough for me..[I felt] a bit sad and negative. (ST820)*

6.1.3 Live demonstration: "tell-show-do" approach

In the first few weeks of the course, students were required to learn about how to use new instruments and materials. They had already gained some procedural knowledge, ie what and when to do, but they had no experience of 'how to do' these activities. For example, how much pressure was needed to cut a cavity in a plastic tooth without burning it, how to create flat/smooth floors or taper the walls without destroying other parts of the tooth, or where to place the mirror to avoid the water spray from the high speed handpiece.

Students identified that having demonstrations with verbal instruction helped them to develop well-defined goals for the subsequent exercise. Although they were shown the procedures they needed to complete as static images, presented using Power Point™, they noted that demonstrations of 'how to do' the whole activity were very useful. Half of the students stated that they learnt more effectively when their tutor showed them how to solve a problem that they were struggling with, eg how to use an instrument appropriately to create a desired outcome and how to control the rotary cutting instrument. Examples of such learning experiences included:

I was not letting the bur to do its job, and instead I was pushing (applying lots of pressure) with handpiece into teeth. This caused lots of noise and didn't efficiently cut the enamel. My tutor realised this, [the tutor] sat down and showed me what to do with my hand piece. Since that session, I have been able to apply what the tutor taught me to all my cavities. This helped me to achieve better quality cavities. (ST322)

I came in for extra sessions over the two week swot vac period and [tutor's name] helped me "fix" my cavity preps. Initially they were large, not smooth, no defined margins. After the sessions, my preps improved because of the intense practice we had. I drilled 10 teeth in 2 – 4 hours. [The tutor] showed me how to manipulate the bur to get a sharp cavity. Tutor showed me, made me practice, saw what I was doing and then explained the exact movements I was making with the bur that were causing the problems. It really improved my cavity preps. They are conservative, more defined, smooth walls and floors. (ST737)

[Tutor's name] showed us how to create cavity and restore cusp protection. It was effective for learning because [the tutor] explained the reasons behind each step and got me thinking. [The tutor] emphasised that it only happens if the cavities have weakened the cusp, ie MI. I've never tried this procedure before so I stopped every stage and tell [the tutor] what I think could be done next and ask [the tutor] for opinion. [The tutor] checked every stage of my procedure. [The tutor] gave me suggestions and told me what to do next and the reasons behind it. (ST317)

The tutor sat down with us and actually showed us the discs and the way they can be used. Also demonstrated some ways of using it on the models. The tutor explained the force required for applying the discs and how to control the movement when producing the desired contour of the tooth. I was always thinking about how to prepare the filling very similar to the way that tutor produced that is very nice and adequate margins and contacts and was thinking to reach that level of perfectionism. (ST947)

When filling the GV black cavities for the 46,47,48 I feel I did a really good job in the end. At first I struggled to get the correct "cusp" shape on the CR, but was shown a good way to do so with the burnisher by my tutor. From here I was very happy with my morphology and felt confident I now know how to do it again. (ST475)

An effective learning experience I had was when I initially used to place an overfilled CR restoration above the margins thinking it was normal. After direction from my tutor he showed me how to utilise the polishing burs, so *that eventually the margins of the cavity could be seen. This was effective in learning how to polish properly. (ST822)*

6.2 Perception about the quality of cavity preparations and restorations: "learning from errors"

In week 9 of the course, 30 students (60%) commented on learning experiences that related to errors they had produced during their cavity preparation exercises. The errors included unsatisfactory aspects of the cavity they produced, eg dimensions of the cavity, including width, depth, taper, smoothness as well as damage to tooth structure perhaps leading to pulp exposure. Students reflected on effective learning experiences as a result of these mistakes that occurred during completion of these exercises, for example:

There were many times where I completely destroyed tooth structure unnecessarily from either being careless or unexperienced. However this was effective for learning since I've learnt from those mistakes. (ST259)

[I] drilled adjacent tooth when doing a proximal slot. Now [I] remember to use matrix bands, learned to leave silver of enamel and remove with hatchet and used soft touches with the bur. Yes it was effective to learn from this mistake and understood how easy it is to damage the adjacent tooth. (ST496)

[I] hit the pulp. I wasn't thinking about the anatomy of the tooth, only trying to remove the decay. [I] didn't judge how I was going which is why I hit the pulp. [It was an] effective [learning experience], [I] know to watch a bit more closely in the future and stop before getting too close to the pulp. (ST293)

Angulation of the bur but was tilted in previous sessions, especially in posterior cavities. [I] practise positioning of the instrument with indirect vision on Frasaco™ at home, got more familiar with the instrument's angulation – improved shape of cavity. (ST891)

Students also reported on effective learning experiences in relation to problems that occurred when completing restorations. The incidents included manipulation of materials and reproduction of dental morphology in restorations. As noted previously, students reflected that mistakes helped them to understand and learn about the quality of their outcomes. One student noted an incident in a laboratory session as follows:

> *I filled the 46, 47, 48, 16 with GIC/CR and polished them and [I] found that overall I overfilled the cavity, and then had to do a lot of polishing. [This] taught me not to overfill and [it is an] effective learning. (ST483)*

6.3 Roles of peers in self-evaluation

Effective learning experiences were acknowledged by students when they discussed their experiences with their peers. As students often encountered similar problems during exercises, they often shared their experiences and effective strategies they had learned from their peers:

> *I found that I was experiencing trouble producing flat floors with the high speed and rounded slow speed burs, but when a fellow student told me to use the flat fissure bur, I found that I improved immensely. (ST688)*
> *Comparing your work with other students. This allowed comparison of what each was finding hard and sharing tips. (ST339)*

6.4 Factors related to operative techniques that influenced the quality of cavity preparation

Students reported several factors that they perceived had affected their cavity preparations such as operative techniques, instrumentation and bur control. In the critical incident reports, more than 60% of students acknowledged that being proficient in the techniques related to the procedures for cavity preparations would help them produce satisfactory outcomes. These techniques involved bur angulation and good vision of the operative field, particularly effective indirect vision (Table 6.1).

While 40% of students indicated that the management of instruments and manipulation of dental materials was important, over the course, 19 students (36%) noted the importance of bur control in completing a cavity preparation. A higher number of incident reports relating to bur control was reported in week 5 of the DCP 2 course (Table 6.1). There were higher numbers of factors in the incident reports in week 8 of semester 2 compared with other time periods during the DCP 2 course. In this week, students completed their first MOD cavity preparation exercises in Frasaco™ teeth in which the internal structure was composed of different materials to differentiate between enamel and dentine layers.

Table 6.1 Factors related to operative techniques that students perceived had influenced the quality of their cavity preparations

No.	Items	Number of reports*				Total
		Semester 1		Semester 2		
		Week 5	Week 9	Week 8	Week 11	
1.	**Operative techniques, eg** indirect vision, angulations of instrument: burs, handpiece, good vision: lighting, visual aids, and restorative skills	18	16	21	10	65
2.	**Instrumentation, eg** selection of different types of burs, manipulation of dental materials, and handling of instruments	9	5	13	5	32
3.	**Bur control, eg** manual dexterity, finger rest, and pressure on bur	15	6	4	3	28

Note: *students reported more than one aspect in each week.

In week 5 of the course, examples of students' comments related to issues with using a rotary instrument for the first time were:

> *It is difficult because I have never handled an instrument like a drill before. I think I need more practice and more time for practice. I find that I take a lot longer to get the hand of the techniques as I never finish on time. It might also be because I am too fussy. [I] focused on using correct techniques and surprised so many people finished early – [I] questioned my own skill. (ST367)*

> *I had trouble controlling the drill, cutting cavities on the maxillary arch. [During the session, I discussed with tutor] to improve vision, seat position and mirror position. This included angulation of the bur head, speed of drilling, as well as accurate cutting. I ended up with cavities too deep in parts, and also too wide. (ST639)*

> *Problems with indirect vision and being able to see during cavity prep. I tried different positions around chair and different mirror placement. I was frustrated that I couldn't see properly and thus tried to adjust my instrument position accordingly. (ST700)*

6.5 Other factors that influenced the quality of cavity preparations

In addition to factors related to operative techniques, students noted other factors that influenced the quality of their cavity preparations. The other factors that were noted in their incident reports included time management, knowledge base, as well as physical and emotional state (Table 6.2). For instance, ST531 and ST618 cited an experience in week 7-semester 2 of the course (see Appendix 6) about time constraints in completing exercises. These involved "doing too many large restorations". This ineffective learning experience led to very tight timing and subsequently, ST618 could not complete the exercises.

Table 6.2 Frequency of non-operative factors that students perceived had influenced the quality of their cavity preparations

No.	Items	Number of reports*				Total
		Semester 1		Semester 2		
		Week 5	Week 9	Week 8	Week 11	
1.	**Time management**	5	7	4	12	28
2.	**Knowledge base, eg** dental anatomy, cavity design (amalgam): GV Black, and preparation for the exercise	8	5	4	5	22
3.	**Physical & emotional, eg** fatigue, tiredness, frustration, stress, and confidence	4	4	2	7	17
4.	**Less experience, eg** inexperience, practice, and ability to work	8	3	0	6	17
5.	**Assessment skill, eg** what is expected, example of cavities, unable to judge, error identification, and requirement of cavities	4	6	1	1	12

Note: *students reported more than one aspect in each week.

6.6 Summary

In summary, students noted both effective and ineffective learning experiences during the DCP 2 operative technique course. The role of the laboratory tutors was found to be important in creating an effective practice environment. Students perceived that they learnt effectively when their tutor set up a group discussion prior to commencing activities and provided positive feedback about their performance. Specifically, students addressed characteristics of feedback that they perceived to be helpful for improving their performance, eg specific feedback with strategies to avoid a similar error in subsequent exercises. Furthermore, students noted that having their tutor demonstrate 'how to do' activities, in addition to visual aids such as the PowerPoint presentations, helped them better understand the procedural knowledge.

In contrast, negative feedback and feedback that focused on mistakes but not on how to improve performance were reported to result in ineffective learning experiences. Students who detected errors that occurred during their activities noted that this helped them to improve their performance. Interestingly, students commented on the role of their peers in the assessment of their performance. Students also perceived other factors influenced their performance, eg operative techniques, assessment skills and their emotional state. The effects of these factors on the quality of performance appear to vary between individuals, and according to stages of learning and types of activities. This is supported by reports of different factors during the course depending on the stage students had reached in terms of their learning.

Chapter 7 – General discussion and conclusions

While new theoretical knowledge relating to the acquisition of psychomotor skills has been applied in many areas, eg sports sciences, physiotherapy and surgery, only a few studies have considered the implications of these theories for the acquisition of skills in dentistry. Internal factors, eg motivational and ability determinants, and external factors, eg the practice environment, have been identified to influence performance of psychomotor skills as noted previously (see Chapter 1, section 1.4). To clarify how these factors relate to the development of cavity preparation skills, the current study was conducted at different stages of learning in two operative technique courses. Phase I involved dental students commencing the third year of their program to explore possible associations between the motivational and ability determinants and students' performance. In addition, Phase I was conducted to clarify how thinking processes of students related to their performance. Phase II was conducted with second-year dental students. This phase helped to clarify whether relationships changed over time and also to identify which external factors influenced the learning environment from a student perspective.

This chapter discusses the findings of the current study in sequence according to the research questions (see Chapter 1, section 1.6). Therefore, section 7.1 discusses results related to the relationship between motivation and performance. Sections 7.2 and 7.3 discuss results related to the relationship between abilities and performance. Section 7.4 discusses results related to students' thinking processes and outlines the use of motor learning parameters when completing cavity preparation exercises. Section 7.5 discusses results related to differences in performance during the exercise.

Section 7.6 discusses results related to external factors that influence learning of psychomotor skills. This is followed by a discussion of the limitations of the current study. The final section considers implications for practice in the design of operative technique courses and possible future directions for research in this field.

7.1 Relationship between motivation and performance

Motivation is one of the essential attributes for learning motor skills (Yarrow et al., 2009). It has been shown to be associated with subsequent learning outcomes (Friedl et al., 2006), especially when a new learning model is introduced to learners (novices). According to motivation theory (Yeo and Neal, 2004), subjective cognitive effort is a key construct which is hypothetically adjusted through goal-setting and self-regulatory processes. These processes are modified in response to changes in the amount of cognitive effort needed to achieve a desired performance level. This construct is influenced by many factors, eg the stage of skill acquisition, perceived task difficulty (Yeo and Neal, 2008) and individual cognitive ability (Kanfer and Ackerman, 1989). Motivational determinants have been reported to influence ability-performance interactions, with low motivation resulting in low levels of performance among both low and high-ability individuals (Kanfer and Ackerman, 1989). In contrast, with high motivation, variability in ability tends to dictate performance. Although the current study did not investigate the roles of motivation as a dynamic construct that can change within individuals in response to environmental factors (Yeo and Neal, 2008), the results did shed light on its importance in the discipline of dentistry.

As noted, the first research question was formulated to clarify whether a relationship existed between motivation and performance in a cavity preparation exercise. The results showed that motivation determined by self-reported effort was positively associated with performance in a cavity preparation exercise undertaken by third-year students. This finding is consistent with the role of motivation in skill acquisition theory (Kanfer, 1990; Yeo and Neal, 2004). It has been indicated that the task difficulty perceived by individuals is also a factor that influences the effort-performance interaction (Kanfer and Ackerman, 1989). For instance, for a normal task, the more effort individuals put into completing the task, the better they perform. However, for a more difficult task, allocating high effort might not result in the desired performance. This provides confirmation that the cavity preparation task used in this study was not perceived by third-year students as being so difficult that they could not reach a desired outcome.

In contrast, a relationship between self-reported effort and performance in cavity preparation was not found in the second-year cohort. Rather, the results showed that the self-reported value of the exercise was associated with performance in the cavity preparation exercise at the end of semester 1 in the second-year cohort. No significant associations were found between a tension factor and performance. This conflicting result might be explained by the fact that these two cohorts completed the motivation survey at different times within the Adelaide dental program, possibly leading to different responses. Specifically, the third-year students completed the cavity preparation exercise after a 12-week break in the course and they were required to demonstrate sufficient competency at that stage of their course to be able to begin treating patients in the clinic. As a result, they may have completed the exercise with more effort to ensure satisfactory completion.

In contrast, the second-year students completed the exercise during a normal class so they might not have been so concerned about the exercise. In fact, at the end of semester 1 when the cavity preparation exercise was conducted, students might have perceived this exercise as providing useful formative feedback on their performance during the initial stages of their learning. This would be consistent with the results showing an association between value and performance. As the exercise was used again at the end of semester 2, students might not have found this exercise as useful as in semester 1 or as the third-year cohort. As the factor loading for some statements in the motivation survey differed from those in the original survey, the characteristics of participants in the current study may have differed from those in the previous study (McAuley et al., 1989). Differences in the context of the study may lead to differences in responses to the survey. For instance, McAuley et al (1989) used a survey that consisted of 18 statements to measure experience with a basketball shooting game of 116 undergraduate students. It appears that the participants in their study volunteered to participate and it was not a class exercise as in the current study. Moreover, the relatively homogeneous nature of the sample in the current study may have limited the chance of detecting negative correlations between the constructs (Marszalek, 2009).

7.2 Relationship between abilities and performance in dentistry

A great deal of research has investigated the potential of aptitude testing as a suitable criterion in the selection of dental students (Spratley, 1990). Many studies have placed emphasis on identifying the validity of tests such as the Dental Admission Test (DAT) - Perceptual Ability Test (Kramer, 1986; Oudshoorn, 2003) and manual dexterity tests (Boyle and Santelli, 1986; Walcott et al., 1986; Gillet et al., 2002; de

Andres et al., 2004; Gansky et al., 2004; Giuliani et al., 2007; Lundergan et al., 2007) in predicting success in dental programs. The results of these studies have shown a range of outcomes and no final conclusion can be made about which tests are the best predictors for success in dentistry. Likewise, previous studies in surgery have shown conflicting results in the relationship between visual spatial ability and surgical performance (Risucci, 2002; Wanzel et al., 2003). While Risucci (2002) found that surgeons showed a higher level of visual spatial ability than the normal population, the study by Wanzel et al (2003) showed that advanced trainees and experts did not score differently on visual-spatial tests. Although ability tests do not show a high predictive value of future success, knowing the level of ability of individuals may assist in identifying problems or overcoming them by designing effective learning environments.

Skill is the level of performance in a task that can be developed through practice and the rate of skill acquisition is influenced by several factors, eg ability (Ackerman, 1988). According to Ackerman's theory of ability determinants of skilled performance (Ackerman and Cianciolo, 2000), there are three major abilities required in each phase of skill acquisition (Fitts and Posner, 1967). In the cognitive phase, cognitive ability (including general intelligence and verbal, numerical and spatial content abilities) is required to understand the procedures involved in a particular task. In the associative phase, perceptual speed ability tends to be relevant to learners to find the most effective way to achieve a task. Subsequently, after repetitively practising a task, learners can then perform skills through autonomous processing with less use of cognitive ability in the autonomous phase. Psychomotor ability is of most importance in completing a task, enabling faster task completion than during the cognitive phase.

Theoretically, this concept of ability determinants of skilled performance could explain how skills are developed in a consistent task involving similar task-components over time (Ackerman, 1988). Several studies have considered the relationship between cognitive ability and motor performance in particular skills, including surgery (Keehner et al., 2006) and dentistry (Gray and Deem, 2002; Gray et al., 2002). The results were consistent with the theory that individual differences in cognitive ability and performance were significantly associated with practice in regard to the consistency and complexity of the task. It has been noted that in tasks that comprise various components involving inconsistent information processing demands, cognitive ability is still needed to achieve the task. Similarly, in a complex task with many critical steps, cognitive ability still plays an important role in contributing to outcomes. This means that for inconsistent stimulus-response tasks such as laparoscopic surgery (Keehner et al., 2006) and dental anatomy and prosthodontics (Gray et al., 2002), skilled performance depends primarily on cognitive ability. This is supported by findings that cognitive ability is strongly related to performance in the last trial of a laparoscopic task (Keehner et al., 2006) and in the grades obtained for a preclinical course (Gray et al., 2002).

Due to conflicting findings in previous studies, the current study used theoretical-designed approaches to clarify a relationship between ability and performance. Broad content ability, as one component of cognitive ability, was found to be an important attribute in enabling an individual to perform at an acceptable level in the cavity preparation task in the second-year cohort. This was consistent with the finding that more than 70% of incorrect aspects of cavity preparation involved the proximal portions of the MOD cavity. It is contended that a class II cavity preparation requires an ability to visualize the desired outcome in three-dimensions. Therefore, broad content ability might be a key factor contributing to a higher level of performance. As noted, students with a high Mental Rotation test (MRT) score were more likely to obtain a higher grade in the cavity preparation exercise over the three time periods. It appears that satisfactory completion of the cavity preparation exercise used in the current study needed an understanding of figural and dimensional perception during the early stages of learning. However, this relationship was not found in the third-year cohort. Given that the two cohorts were at different stages of learning, it is possible that cognitive ability was required to achieve a satisfactory cavity preparation outcome in the second-year cohort who had less experience in cavity preparation tasks. Due to the relatively small number of students in the second-year cohort, future studies with greater numbers of participants are needed to confirm these findings.

The results showed that psychomotor ability was positively associated with a higher level of dental performance in the third-year cohort. However, there was an interaction effect of Tapping-sex on grades. There was a difference between the sexes for the higher score Tapping sub-group, ie female students in this group were more likely to outperform male students. However, an interaction was not found in the lower score group. In the second-year cohort, psychomotor ability (MacQuarrie: Tracing subtest) was also found to be a key ability that contributed to a higher level performance on the cavity preparation exercises over time, ie from initial pre-learning to semester 1 and 2 preparations. Results on the relationship between the score on psychomotor ability tests and dental performance were consistent with those of a previous study to some extent (de Andres et al., 2004). In the study by de Andres and colleagues (2004), a range of psychometric tests, including the O’Connor Tweezer test and the MacQuarrie test for mechanical ability, were used to evaluate psychomotor skills at the end of an academic term. These researchers found a significant difference in scores obtained for the two tests between students with higher and lower practical results. Students with higher marks from practical activities tended to obtain higher scores in the Tracing and Dotting subtests. In addition, those students with lower practical results spent longer completing the O'Connor Tweezer test. However, as the dependent outcomes were grades that students achieved from a range of practical courses in their program, the results might not be directly comparable to those in the present study.

7.3 Administration of psychometric tests: does the timing matter?

Factors that need to be considered in explaining the results of this study include the optimal timing for measuring ability and the study design. One might question whether the administration of psychometric tests after the third-year students had been involved in a range of laboratory exercises could have affected the results of the tests. However, ability is defined as an 'inherent' trait, and one's ability measured using standardised tests should not change with practice (Schmidt and Lee, 2005). Indeed, a recent 4-year study showed that there was no significant difference in time spent to complete Tweezer tests from the beginning to the end of a dental curriculum (Lundergan et al., 2007). This suggests that the scores obtained by third-year students for the psychometric tests were unlikely to have changed even though they had completed a one-year practical course.

The different characteristics of measured outcomes in terms of the scale of measurement might also result in conflicting findings. An objective measurement is required to provide valid interpretation about measured outcomes (Ackerman and Cianciolo, 2000). For instance, in Ackerman and Cianciolo's study, an objective measurement of performance in an air-traffic control task was to count the number of aircraft that participants could land safely and also the number of errors that occurred. Likewise, Keehner et al (2006) objectively measured time spent in completing a simulated laparoscopic task. In our study, we selected a basic task in operative dentistry and measured the quality of skilled performance determined by a grade for the cavity preparation rather than using grade point averages from various technical courses. In addition, the relatively small number of collected cavity preparations and the study design compared with these other studies might limit the generalisability of the findings. In the current study, data collection was completed in a normal class environment during which students were involved in a range of tasks that required factual and procedural knowledge to achieve a satisfactory outcome. Multiple trials of a particular task administered in an experimental study design, as in other studies, are not realistically implemented in a dental education context. To address this issue, the number of exercises related to the MOD cavity preparation was increased in Phase II of the study. The results from Phase II of the current study were consistent with the results from Phase I where a relationship between psychomotor ability and dental performance was found.

In summary, if we consider abilities related to stages of learning using Ackerman's theory of skill acquisition, it appears that skilled performance in third-year and second-year dental students developed after participating in an operative technique course. In the initial stages of learning cavity preparation skills, ie for second-year students, cognitive ability, specifically broad content ability, was a key factor associated with a higher level of performance in the selected exercise. This ability was still associated with the performance in the later stages of learning in the second-year cohort. Psychomotor ability was also positively associated with performance during the learning period in second year. As this exercise was performed using a plastic typodont tooth without caries, students were required to do similar exercises following certain criteria, eg depth, width and cavity outline. It is likely that students developed task-specific ability, eg how to move the bur smoothly to create the cavity outline, with reduced demand on cognitive aspects. Moreover, with the consistent characteristics of the required cavity design, students probably strengthened the skills needed to accomplish the exercise. At the same time, it appears that broad content ability was also required to facilitate three-dimensional depth perception when cutting an MOD cavity preparation.

Given the supposed relationship between ability and performance in Ackerman's theory, we could apply this knowledge to help identify students who might have difficulty in learning skills in dentistry. However, as the results of this study did not show strong evidence of a lower level of performance in relation to a lower level of ability, ability tests might not be the most important tool to assess an individual's capacity to learn these skills. Although ability was a significant predictor that determined inter-individual differences in the level of performance, this influence seemed to be overcome with practice during the DCP 2 course. This is evident by the improved grades that students obtained for the cavity preparation exercises over the three measurement periods (see Chapter 4, section 4.5). Based on the higher level of performance of both cohorts related to the reference groups for all psychomotor tests, it might be that dental students represent a special group with greater capacity to perform well in psychomotor skills used in dentistry (Hudson, 1966). With relatively small differences between students, there is a limited range of performance and, therefore, it is difficult to find tests that can predict individual differences in performance (Ericsson et al., 2006). For instance, if scores of psychomotor ability were related to grades for cavity preparation and a score of at least 50 was enough to perform well in an exercise, students who received test scores above this threshold would be unlikely to show differences in performance on the related exercise. Therefore, it would have been difficult to find an absolute relationship between ability and dental performance among the dental student group. Therefore, instead of focusing solely on inter-individual differences, it might be useful to place an emphasis on or investigate intra-individual differences in the development of learning components throughout practice. Learning components related to motor learning theory (Schmidt and Lee, 2005), eg knowledge of results, have shown substantial effect on performance and they are developed through practice (see Chapter 1, section 1.4.3). Therefore, an understanding of students' thinking processes during the completion of the task would inform relevant components related to their performance.

7.4 Processes and outcomes: relations to dental performance

It is unlikely that one factor, ie ability or motivation, can solely explain how skilled performance develops in students (Rose and Christina, 2006). Other factors such as in how students understand what they need to do and are aiming to achieve also influence performance. Four learning parameters have been shown to play an important role in learning new skills (Feil et al., 1986; Feil and Reed, 1988; Schmidt and Lee, 2005). These parameters are related to identification of desired outcomes and performances as well as the identification of errors during a task (see Chapter 1, section 1.4.3). It is likely that a greater understanding of the learning parameters that students were developing during the cavity preparation exercises would help to explain motor performance.

7.4.1 Visual representation and performance

The present study revealed that most students tended to use visual representations of their desired outcomes during their cavity preparations rather than using written descriptions. Consistent with the literature, two key characteristics were revealed from the interview reports. These characteristics were the types of mental representation used and the types of intrinsic feedback the students used to complete the task. One might expect that students with better visual representation would perform better in a dental task than those whose understanding was based on verbal representations. It is likely that the generation of visual representations, which can be referred to as non-verbal thinking, might help learners perform better in a manual task. In relation to this study, therefore, we might expect that students who have pictorial representations would have better recognition memory contributing to precise details of a desired outcome. However, this was not apparent in this study. The results showed that most students in both sub-groups tended to use visual representation of their desired outcomes rather than using verbal aspects, ie instructions and criteria for cavity preparation. This was also supported by the significant relationship noted between the accuracy of students' sketches and their performance in cavity preparations (see Chapter 4, section 4.8). This finding is consistent with a previous study (Feil and Gatti, 1993) that compared dental practitioners and dental students. The study found that practitioners visualised details of anatomical landmarks, such as fissure systems and cusp positions of a tooth, rather than cutting a cavity based only on verbal descriptions provided in a laboratory manual. The current findings are also consistent with those of Gillet et al (2002) who found that drawing ability was a good predictor of good practical work, specifically in making a cavity in a resin tooth. The findings from this study provide some support for a significant relationship between visual representations and outcomes of a cavity preparation, but they did not show differences in visual representation between higher and lower performance sub-groups. It might be that differences in performance between the sub-groups were not great enough to show differences in thinking processes and this was supported by the range of results from the observational study. For instance, there were no differences in time spent for each activity during cavity preparation between the sub-groups (see Chapter 5, section 5.2.1). Further comparative studies investigating this issue using more experienced students would appear to be warranted.

7.4.2 Roles of feedback in enhancing skill learning

A second characteristic that students reported they used when completing their preparations was highlighted in the retrospective think-aloud interviews. It related to the role of feedback in enhancing skill learning. In Phase I of the current study, students needed to use self-controlled feedback to complete the exercise as external feedback from tutors was not provided. This meant that they were dependent solely on their own intrinsic (sensory) feedback. This feedback may include visual, auditory, proprioceptive and cutaneous feedback (Rose and Christina, 2006). Since this feedback serves as a guide to correct undesirable outcomes or performances, it could be argued that more advanced learners would be more likely to perform movement evaluation accurately (Rose and Christina, 2006). This means that if students can readily detect errors, they should know how to solve those errors with an alternative approach. However, if they do not perceive that an actual outcome they have created is an error, even though the error may be obvious, then they would tend to use a similar strategy subsequently, leading to repetitive errors (Reason, 1990)

One of the key aspects in Schema theory is feedback in terms of 'when' and 'how much' feedback is needed (Schmidt and Lee, 2005). According to this theory, it is expected that feedback focused on knowledge of results (KR) and knowledge of performance (KP) is preferred to encourage motor learning. Feedback focused on knowledge of results has been found to be beneficial to skill learning using virtual reality with the appropriate frequency (Wierinck et al., 2005). In the study by Wierinck and colleagues, provision of frequent feedback showed learning advantages for cavity preparation but not in a retention test (no feedback provided). A recent study showed that a suturing and knot-tying task in a laparoscopic simulator could be learnt effectively with feedback from the device, only on KR (O'Connor et al., 2008). The group who had been provided with KR, eg time, path length as well as what mistakes had been made, showed no difference in their performance compared with those who had been provided with only KR. However, generalisation of the results from the study of O'Connor et al (2008) might be limited due to the small sample sizes and the simplicity of the task used in their study.

In contrast, in a self-guided learning approach, a group with process goals demonstrated greater benefits in learning surgical skills than those with outcome goals (Brydges et al., 2009). Participants in both groups viewed an instructional video of an expert performing a wound closure skill, but those who were assigned to complete the task with process orientation showed greater retention of the skill than those with goal orientation. Process orientation is similar to desired performance as it includes information about subsequent processes that are needed to achieve a task. Further studies are needed to determine whether augmented feedback focused on performance could lead to better skill learning.

Interestingly, key aspects related to process, eg at this stage of their learning, students from both cohorts did not consciously plan the angulation of the bur when cutting a cavity. This result is inconsistent with a previous study (Feil and Gatti, 1993) in which dental students were more conscious than dental practitioners about bur position. However, data drawn from verbal self-reports in the latter study might not be reliable, as the self-reports were not obtained immediately after the task. As noted in section 1.4.3, short-term memory has been shown to play a significant role in the accuracy of verbalisation (Nielsen et al., 2002). Thus, due to the variable length of time after the processing of information for completing the task, subjects might not have remembered accurately what they were thinking during task completion.

In the second-year cohort, students acknowledged the influence of tutor feedback on their performance (see Chapter 6, section 6.1.2). Negative feedback was perceived by students to produce an ineffective learning experience. This finding is consistent with a recent study assessing factors that influence learning in the dental school clinic where students showed concern about condescending feedback from their tutor (Henzi et al., 2006). As expected, positive feedback with specific information was noted to provide effective learning experiences. In fact, specific feedback is a relevant component in deliberate practice needed to develop expert performance (Ericsson, 2008). This finding is consistent with previous findings in surgery (Bannister et al., 2003; Thuraisingam et al., 2006) and dentistry (Victoroff and Hogan, 2006). Positive and deliberate focused feedback was noted to be useful in learning technical procedures in a neonatal intensive care unit (Bannister et al., 2003) and in endoscopy training (Thuraisingam et al., 2006). However, there was no clear evidence to show the relationship between successful learning outcomes and the content or frequency of feedback.

7.5 Differences in performance during a cavity preparation exercise between higher and lower performance sub-groups

Quantitative data collected from observations did not show significant differences between the two sub-groups of students in the third-year cohort, who had been classified according to their performance levels using outcome measures. Initially, it was expected to see differences between these two sub-groups based on the assumption that those students who could consistently produce a satisfactory outcome would have developed motor learning parameters at a more advanced level than those who achieved unsatisfactory outcomes. This assumption is based on differences between experts and novices in performing a dental task (Feil and Gatti, 1993). Specifically, those students from a higher performance sub-group might be expected to perform a task more smoothly than those from a lower performance sub-group. For example, a previous study showed that dental practitioners operated more smoothly than dental students (Chambers and Geissberger, 1997). However, in the current study it appears that there were no fixed patterns in the way those students who demonstrated a higher level of performance went about achieving the expected outcome. The students had developed their motor learning parameters and the characteristics of these parameters varied individually. For example, in the higher performance sub-group, one student preferred to have a visual representation of a desired outcome whereas another tended to perform the task following verbal instructions. The lack of differences between the sub-groups might be explained by the fact that differences in performance between them were not as great as those between students and practitioners.

By comparison with the third-year cohort, differences in performance between lower and higher sub-groups were noted in the second-year cohort five weeks after they had commenced the course. Students in the lower performance sub-group tended to stop and evaluate their outcome more frequently than those in the higher performance sub-group. The results of the current study were consistent with a study conducted by Chambers and Geissberger (1997), which showed that competent students tended to perform more smoothly than beginners due to the use of their 'internalized schema' to guide performance. This indicates that students in the higher performance group had developed appropriate motor learning parameters that enabled them to achieve their desired outcome.

As noted, differences between the two sub-groups were not found in the third-year cohort but only in a particular period in the second year. This might be due to the complexity and numbers of exercises that students had completed. In a simple cavity preparation exercise such as an occlusal cavity preparation, which was completed in week 5 and 6 of the course, students displaying higher levels of performance would have learnt and developed skills which they would retain for similar exercises in subsequent sessions. In contrast, it is likely that an MOD cavity preparation exercise was considered to be a more complicated exercise that needed a higher level of skill than an occlusal preparation. Students might have developed a set of rules needed to achieve a satisfactory outcome by week 5 of the course, and this was supported by fewer adjustments in operations during the completion of the exercise in week 6 (see Chapter 5, section 5.2.2). This finding is consistent with a recent study in which participants whose environment was constrained to reduce error showed a higher level of performance than those who learnt in an environment that promoted error in late stages of learning (Poolton et al., 2005).

7.6 External factors that influenced learning of psychomotor skills: the practice environment

External factors such as the practice environment also play an important role in supporting the learning of new skills (Rose and Christina, 2006). In fact, the practice environment is a factor that needs to be considered when designing learning activities (Rose and Christina, 2006). The practice environment includes the arrangement of the practice schedule in terms of the sequence of tasks, the amount of practice, and the variability of exercises. For instance, an implicit learning approach has been shown to promote better performance in golf putting than an explicit learning condition (Poolton et al., 2005; Masters et al., 2008). Currently, it is not known which practice environment is effective in each learning context. To explore the issue of an optimal practice environment, information on students' perceptions should be valuable. Therefore, Phase II of the current study aimed to clarify which were the aspects of the courses that students perceived as providing 'effective' or 'ineffective' learning experiences. Several themes were derived from critical incident reports and follow-up interviews. The role of tutors in confirming correct performance was a key factor that students perceived to influence their learning of cavity preparation skills. These findings are consistent with a previous study (Victoroff and Hogan, 2006) that investigated the perceptions of students about learning experiences in dental school. Preferable characteristics of instructors included positive and interactive styles where they demonstrated and shared their experience with students.

Theoretically, when learning a new task, a learner initially uses trial and error approaches to achieve a goal for the task (Fitts and Posner, 1967). The learner subsequently develops a reference derived from corrective feedback through self evaluation and/or guidance from teachers to decrease errors in performance (Schmidt and Lee, 2005). In fact, verbal feedback from experts enables students to learn new surgical skills better than self-accessed feedback (Porte et al., 2007). For instance, in the DCP 2 operative technique course, students used self-regulated or self-controlled feedback, ie they learnt from errors detected during practice and refined their performance. With augmented feedback from tutors, students modified their movement or strategies to cut a cavity more precisely. Therefore, it is crucial for tutors to point out the nature and cause of errors in the early stages of learning so that the correct movement can be developed by students with repeated practice. However, it seems that students preferred to receive positive feedback rather than negative feedback. Negative feedback might cause students to be less motivated to complete a task and this might result in a lower level of their performance (Langan-Fox et al., 2002). Consistent with students' preference for positive feedback, a recent study revealed that feedback received after a good performance in a trial enhanced learning of a new skill (Chiviacowsky and Wulf, 2007). In this study, participants were required to throw beanbags to a target with their nondominant arm. Participants were allowed to see the target before throwing but they were blinded to outcomes during and after the task. A group of participants who received knowledge of results (KR) related to their most effective trials showed better learning outcomes in retention tests (without KR) than a group who only received KR about their least effective trials.

7.6.1 Demonstration: learning implicitly by observation

Second-year students were required to learn a new skill, ie cavity preparation, using various sources of information. One of the potential sources was learning by observing a demonstration by an expert. In fact, observational learning has underpinned learning of surgical skills (Custers et al., 1999). For example, a recent study examined how observational learning influenced implicit and explicit motor learning of suturing skills in surgery (Masters et al., 2008). The results showed that participants who learned implicitly by observation alone or by observation accompanied by guidance could perform suturing tasks during multi-tasking. According to the implicit motor learning perspective, skills are acquired through two pathways, ie declarative and procedural learning pathways (Masters, 2004). The declarative pathway is involved with generation of strategies using information derived from self error-detection or modification following verbal instructions. The procedural pathway is developed in parallel with the development of declarative knowledge and this pathway cannot be verbally described by learners. The latter learning pathway is promoted in highly consistent learning conditions, ie the introduction of errorless approaches would enhance better procedural learning pathways resulting in better outcomes and performance (Maxwell et al., 2001). This is consistent with students' perceptions of the value of demonstrations by their tutor as noted earlier in Chapter 6, section 6.1.3. This suggests that tutors should guide students at the initial stages of skill learning in 'how to do' with errorless approaches to experience the desired outcome and process. This means that the introduction of well-designed demonstrations for dental students in the early stages of learning can promote high quality understanding of expected outcomes and processes.

7.6.2 Learning from peers: impact on learning of skills

Strategies involving peer learning have been shown to support the understanding of knowledge and practical skills, eg Goldsmith et al (2006) and Nikendei et al (2008). In Goldsmith's study, first and third-year nursing students participated in peer learning to increase their understanding of competency standards for practice. One practice session was used each week, in addition to their normal class, in which third-year students facilitated first-year students to learn simple tasks, eg a simple dressing. This occurred under the supervision of their lecturers. At the end of the study, students noted valuable aspects of this strategy in supporting their skill learning. Similarly, in Nikendei's study, final-year medical students were assigned as peer tutors with groups of third-year medical students. At the end of their program, both levels of the students acknowledged the value of these activities to support their learning of clinical skills.

In the current study, the results were consistent with previous findings that peer learning was valued as a useful tool for developing self-evaluation skills. As the students had a limited number of exercises during which they could practise these skills, peer learning provided them with extra opportunities to practise and simultaneously promoted a collaborative learning environment. This approach has been adopted by nursing with both undergraduate and postgraduate students and it has been acknowledged to enhance learning skills, eg reflective and critical thinking ability (Loke and Chow, 2007). This system provides students with an opportunity to identify inadequacies and to correct misunderstandings. However, as students in the current study were at similar levels of experience, inadequate knowledge of peers could lead to negative outcomes. In peer tutoring, students who play the tutor role should receive sufficient training to ensure adequate competence to foster a positive learning environment (Loke and Chow, 2007; Weyrich et al., 2008).

7.7 Strength and limitations of the current study

As far as the candidate is aware, based on published literature, this is the most comprehensive study of factors associated with the development of psychomotor skills in dental students. The novel aspects of the study include that it draws explicitly on relevant theories of skill development (see Chapter 1, section 1.4), it incorporates a longitudinal element in the study design, and it uses mixed methods (see Chapter 2, section 2.3 and 2.4), ie quantitative and qualitative approaches, to analyse the findings. It is considered that the findings add to our understanding of factors influencing skill development in general as well as providing valuable insights into how effective learning programs might be designed for operative skill development in oral health professions.

Despite the strengths of this study, some limitations should be noted. The current study was designed as an exploratory study where data were collected in a real-life environment, so some limitations need to be acknowledged in the interpretation and generalisation of the results. Firstly, although the candidate had estimated the numbers needed to detect significant relationships between variables of interest, this was not be able to be achieved fully as there were fewer students in the second-year cohort than anticipated. Secondly, some differences in teaching approaches occurred in the courses (as discussed previously in Chapter 2, section 2.2), eg different tutors and sequences of learning activities. This may have affected learning outcomes to some extent. Thirdly, the factor loadings for some statements in the motivation survey were different to those of the original survey and this influenced the internal structure of the survey (see Chapter 3, section 3.1.4). Fourthly, grading systems used in this study provided categorical data and this limited the power of correlation analyses between factors of interest and performance. Finally, the few trials observed limited the opportunity to investigate in depth changes in dependent outcomes over time. To minimise the effects from this limitation, Phase II of the current study used a longitudinal approach to collect multiple samples in the second-year cohort.

7.8 Implications for practice and future research

The current study showed that there were several factors that can influence the acquisition of skills in operative technique courses in dentistry, including intrapersonal factors, eg motivation and ability, and also external factors, eg the practice environment. These findings could be used to inform the design of learning activities in operative technique courses. The following section outlines implications of the key findings for practice and provides suggestions for future research.

7.8.1 Providing suitable learning activities to encourage motivation

As stated previously in Chapter 1, section 1.4.1, motivation in terms of the cognitive effort that individuals allocate to a task is modified according to the cognitive information-processing demands for completing the task. This means that the arrangement of suitable learning activities matched to the level of complexity of the task should encourage effective learning of skills. As individuals use different ways to learn effectively (Dunn and Griggs, 1995), designing learning activities to match their capacity should help them learn appropriately. For instance, students who learn well with visual aids might need additional sources of learning materials compared with other students. A recent study has shown a significant relationship between individual learning styles and psychomotor skill performance using a laparoscopic virtual reality simulator (Windsor et al., 2008). Students and tutors might need to evaluate learning outcomes routinely, resulting in 'tailored' learning activities. A recent study investigating learning styles among general surgeon residents showed that there were variable learning styles between the sexes (Mammen et al., 2007). It appears that dental programs could be tailored to suit the individual by designing a variety approaches for content delivery that better meet the learning style of individuals. However, no research into learning styles and dental psychomotor skills has been undertaken. Future studies investigating preferred learning styles in the context of learning dental psychomotor skills and examining theoretical models that match those styles would help in the design of effective learning environments.

Another possible approach might be assisting students in setting their goals for each laboratory session, as individuals tend to adjust their effort allocated to a task according to information-processing demands of the task (Locke and Latham, 2002). Future studies might focus on the evaluation of different sequences of learning activities and their effect on motivation in relation to learning outcomes.

7.8.2 Strengthening ‘what is an expected outcome’ using visual representation

The results of the current study support the use of visual representation in supporting learning in operative dentistry (see Chapter 4, section 4.8). It might be valuable for students to gain a clear picture of the expected outcome for a cavity design by asking them to draw their planned expected outcome before commencing any cutting. This would help tutors gain an understanding of students’ perceptions of the exercise. Drawing a desired cavity outline from different views in three dimensions should help students transfer the image to their actual cavity. Moreover, this might help tutors identify students who have difficulty in applying knowledge of cavity dimensions in practice, as noted previously in Chapter 5.

Multimedia instruction can be a relevant source that encourages the development of this visual representation. For example, it was noted by the second-year students that knowledge of the desired outcome was derived from a range of sources including pictures in course materials (see Chapter 5, section 5.3.1). The design of the instructions based on the science of learning and the science of instruction should assist students’ understanding and learning relevant knowledge (Mayer, 2008) and hopefully, skills required in operative dentistry. The science of learning focuses on how individuals learn through their cognitive processing while the science of instruction focuses on how to help individuals learn using appropriate instructions. For instance, a PowerPoint presentation showing cavity preparation procedures with narrations might be enough to foster an understanding of the procedures without having extra text on the screen. This extra information could form ‘extraneous information’ that would place unnecessary load on cognitive processing and distract students from the relevant information.

7.8.3 Providing live demonstrations of procedures

Demonstrations of procedures have been used commonly in teaching skills in health professions (Custers et al., 1999). In the current study, this approach has been acknowledged by students to provide an effective learning experience (see Chapter 6, section 6.1.3). As there was a lack of use of desired performance and knowledge of performance by students (see Chapter 5, section 5.3.2), it appears that they need learning approaches that provide information related to the processes of a task. Learning by observation is a conventional approach for learning skills in many areas, eg surgery and sport sciences (as noted previously in 7.6.1). A recent study has shown interesting aspects of integrating this concept with implicit motor learning into teaching surgical suturing skills (Masters et al., 2008) and these concepts could be extended to dentistry. The results of the study showed that in a given exercise, the reduction of unnecessary information related to 'motor knowledge' should increase memory for cognitive information processing for other critical decisions. For instance, this learning method should be of benefit for surgeons when they have to monitor their patients' condition while operating. These approaches might provide a basis for the next step in teaching operative skills in dentistry which traditionally uses observational learning. For example, a demonstration of how to move a bur while cutting a cavity might be more realistic than identifying correct bur angles on static images. As students had no experience of 'how to do', they noted that they learnt more effectively when their tutors performed a task (see Chapter 6, section 6.1.3). Future studies aimed at identifying those aspects of cavity preparation that involve 'motor knowledge' would help in deciding the scope of instructions needed for learning these skills. Furthermore, an intervention-designed study investigating learning outcomes from different teaching approaches based on managing 'motor knowledge' could be used to review course designs.

7.8.4 Organising peer-assisted learning for supporting self-evaluation skills

Although there is little evidence that peer-assisted learning has contributed to superior psychomotor skills, as discussed previously, this strategy might be useful in developing self-evaluation skills related to motor learning parameters. A key component in motor learning involves recognition schema which are responsible for identifying errors when completing a task (see Chapter 1, section 1.4.3). At the stage of learning in the DCP 2 course, students tend to adopt trial and error approaches in their exercises, according to acquisition theory and also according to findings from critical incident reports from the current study. This provides a potential opportunity for them to discuss and learn from each other's mistakes while still under the supervision of a tutor. Learning activities that allow students to assess their work and make comparisons with peers should strengthen their visual representation of desired outcomes and also knowledge of results. For instance, in week 5 of the DCP 2 course in Adelaide, when students prepare an occlusal cavity for the first time, there could be a session where students are provided with an opportunity to discuss errors that have occurred in the first trial. The causes and possible solutions of these problems could be discussed in a group or at an individual level. The various errors noted would provide a range of visual templates for making comparisons between the desired outcome and the 'actual outcome' (knowledge of results). The variety of practice should theoretically be recorded in recall schema and recognition schema and this hopefully would lead to effective learning of skills.

7.8.5 Providing staff development for operative technique laboratory tutors

As noted previously in section 7.8.3, the results suggest that demonstrations and quality feedback given by tutors were perceived to support skill learning by dental students. It is important to ensure that these components are taken into account when designing operative technique courses. For instance, it is clear that specific training sessions should be held for laboratory tutors to enable them to provide effective demonstrations as well as quality feedback to students.

7.9 Conclusions

The findings from this study provide new insights into the factors that influence learning of psychomotor skills in operative dentistry including the roles of motivation and ability. Three main conclusions can be drawn from the findings. Firstly, there was a significant association between motivation, including perceived value and the effort expended, and performance in both cohorts. Specifically, the value that the second-year students placed on the cavity preparation activity was associated with performance, while for third-year students, it was their effort that was associated with performance. In terms of ability, performances in a cavity preparation exercise were influenced by psychomotor ability in the both cohorts and performances in the second-year cohort were also associated with broad-content cognitive ability. The latter relationship remained important in the last trial in the second-year course in operative dentistry. To some extent these findings are consistent with the theory of ability determinants of skilled performance proposed by Ackerman (1988), with the relationship between ability and outcome performance changing at different stages of learning, as discussed previously in section 7.2. It is concluded that motivation and ability, including both cognitive and psychomotor ability, are key factors that influence learning outcomes in operative dentistry. These outcomes have important implications for the design of learning activities, such that dental educators need to design activities that maximise students' motivation which may vary depending on their stage of learning. Recognising variations in performance related to ability may be useful for identifying students who need extra practice to achieve a satisfactory standard of performance.

Secondly, there were no significant differences in the use of motor learning parameters during completion of cavity preparation exercises between students chosen from the ends of the performance range. In both sub-groups, students who drew well-defined sketches of cavity outlines demonstrated satisfactory outcomes in the exercises. In general, students from both higher and lower performance sub-groups tended to focus on evaluating outcomes only, rather than focusing on processes as well as outcomes. These findings indicate that the accuracy of students' understanding of the outcomes they were trying to achieve was important in achieving a satisfactory standard. It is also concluded that while outcomes were routinely evaluated, students' use or understanding of the processes required for a cavity preparation was limited. As a result, we need to design activities that improve students' understanding of the processes needed for the completion of cavity preparations as well as their understanding of the outcomes they need to achieve.

Finally, effective learning experiences were noted when tutors arranged group discussions about 'how to do' exercises and also gave live demonstrations with explanations and 'tips' based on experience. Moreover, positive feedback was noted to promote better performance that helped students identify strategies to improve.

Ineffective learning experiences were noted when students were unsure and become stressed about their knowledge base of ‘how to do’ the exercises. Negative feedback from tutors without specific suggestions about how to improve performance was perceived to lead to ineffective learning experiences. Students acknowledged the role of tutors in supporting skill learning in the operative technique courses through providing appropriate guidance. These findings highlight the critical need to provide staff development for our laboratory (and clinical) tutors that specifically addresses contemporary approaches for establishing positive learning environments and providing effective feedback to students.

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Appendices

Appendix 1 – List of achievements and professional development activities of Nattira Suksudaj during PhD candidature 2006-2010

Research grants

- Winning T, Suksudaj N, Lekkas D, Townsend G and Kaidonis J (2006) School of Dentistry, The University of Adelaide. Internal Research Grant. Development of clinical skills in dental students ($3,000).
- Winning T, Suksudaj N, Lekkas D, Townsend G and Kaidonis J (2007) Australian Dental Research Foundation (ADRF). The development of psychomotor skills in dental students ($12,499).
- Winning T, Suksudaj N, Lekkas D, Townsend G and Kaidonis J (2008) Australian Dental Research Foundation (ADRF). Factors influencing dental students' learning of psychomotor skills ($8,500).
- Winning T, Suksudaj N, Lekkas D, Townsend G and Kaidonis J (2008) Education Research Group Grant (IADR-ERG). Psychomotor skills development in preclinical dental students ($US1,000).

Travel award

- Suksudaj N (2009) Colgate post-graduate student travel award, International Association of Dental Research (IADR) (Reimbursement for conference cost and airfares).

Published abstracts for conference presentations during candidature

- Suksudaj N, Winning T, Lekkas D, Townsend G and Kaidonis J (2007) The development of psychomotor skills in dental students. In: Enhancing Higher

Education, Theory and Scholarship, 30th Higher Education Research and Development Society of Australasia (HERDSA) Annual Conference [CD-ROM] Adelaide, South Australia.

- Suksudaj N, Winning T, Lekkas D, Townsend G and Kaidonis J (2008) Internal factors influencing learning of psychomotor skills by dental students. In: Practice, Scholarship and Research, Health Professional Education of the Association of Health Professional Education (ANZAME) Annual Conference. University of New South Wales, p116-117.
- Suksudaj N, Winning T, Lekkas D, Townsend G and Kaidonis J (2008) Internal factors influencing learning of psychomotor skills by dental students. In: Proceedings of the Colgate Australia Clinical Dental Research Centre Research Day, Adelaide.
- Suksudaj N, Winning T, Lekkas D, Townsend G and Kaidonis J (2008) Internal factors influencing learning of psychomotor skills by dental students. Australian Dental Journal 53:S39.
- Suksudaj N, Winning T, Lekkas D, Townsend G and Kaidonis J (2009) What factors influence learning of psychomotor skills by dental students?. In: Proceedings of the Colgate Australia Clinical Dental Research Centre Research Day, Adelaide.
- Suksudaj N, Winning T, Lekkas D, Townsend G and Kaidonis J (2009) What factors influence learning of psychomotor skills by dental students?. 2nd Meeting of the International Association of Dental Research (IADR) Pan Pacific federation (PAPF), the 1st Meeting of IADR Asia/Pacific Region (APR) and the

47th Annual Meeting of the IADR Australia and New Zealand Division, Wuhan, China.

Other professional development activities

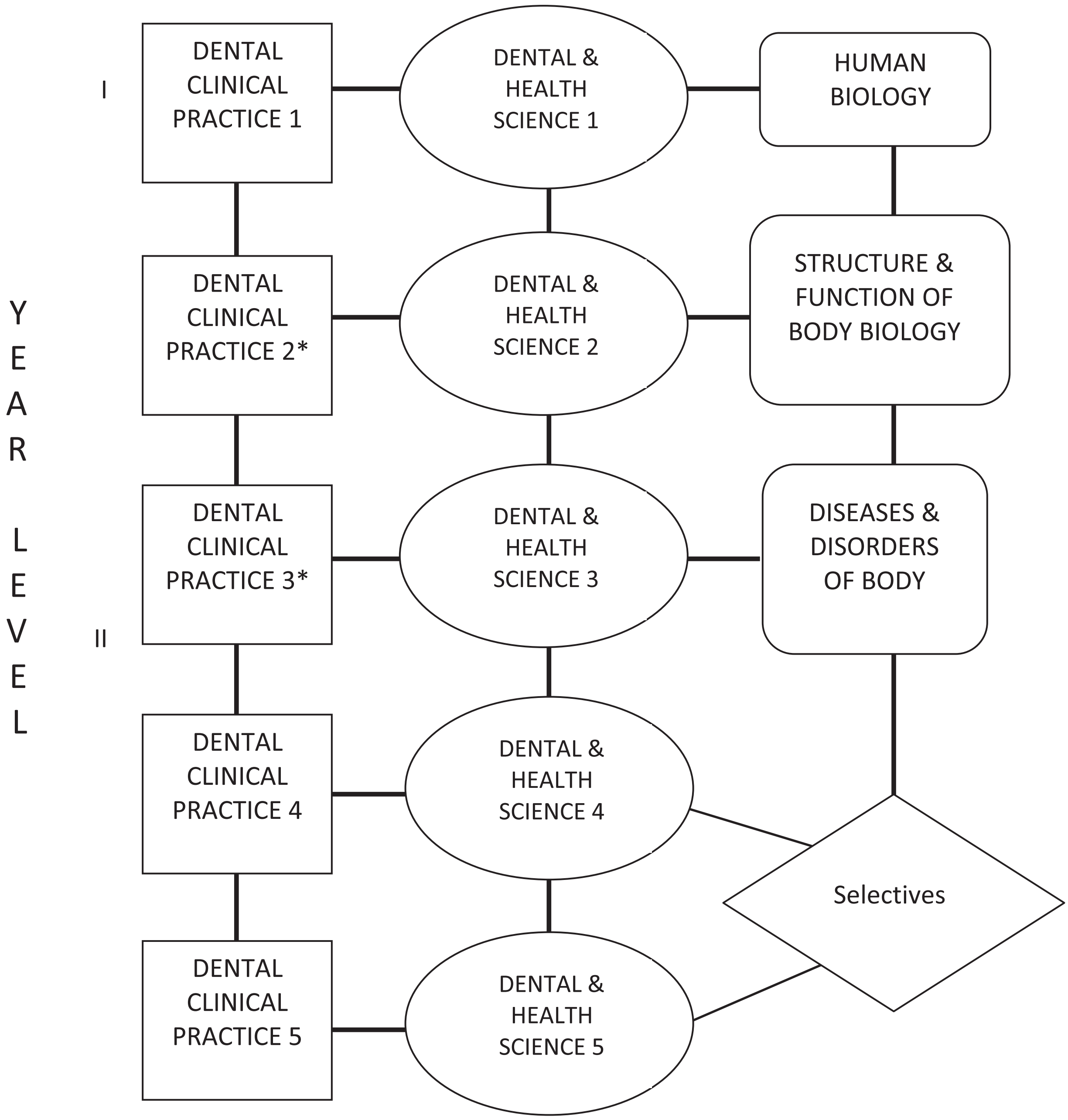
- Co-supervision of undergraduate student research projects

  Dental education student vacation research project: Ying Gu (2008-2009) The validity of cavity preparation exercises in measuring motor performance (Winning T, Suksudaj N).

- Visited the Centre for Education and Training, Department of Surgery, Faculty of Medicine, The University of Hong Kong (28 September 2009)
  - Had discussions with Professor Nivritti Gajanan Patil (Director) about methods used for training surgical skills in trainees.
- Visited the Faculty of Dentistry, The University of Hong Kong (29 September 2009)
  - Had discussions with Dr Susan Bridges (Assistant Professor in Dental Education and E-Learning) about current research projects in relation to dental education at The University of Adelaide and The University of Hong Kong
  - Visited the simulation laboratory used for training dental skills in dental students.
- Visited the Institute of Human Performance, The University of Hong Kong (30 September, 2 October 2009)
  - Gave an invited seminar to the Institute staff and had discussions about current research projects

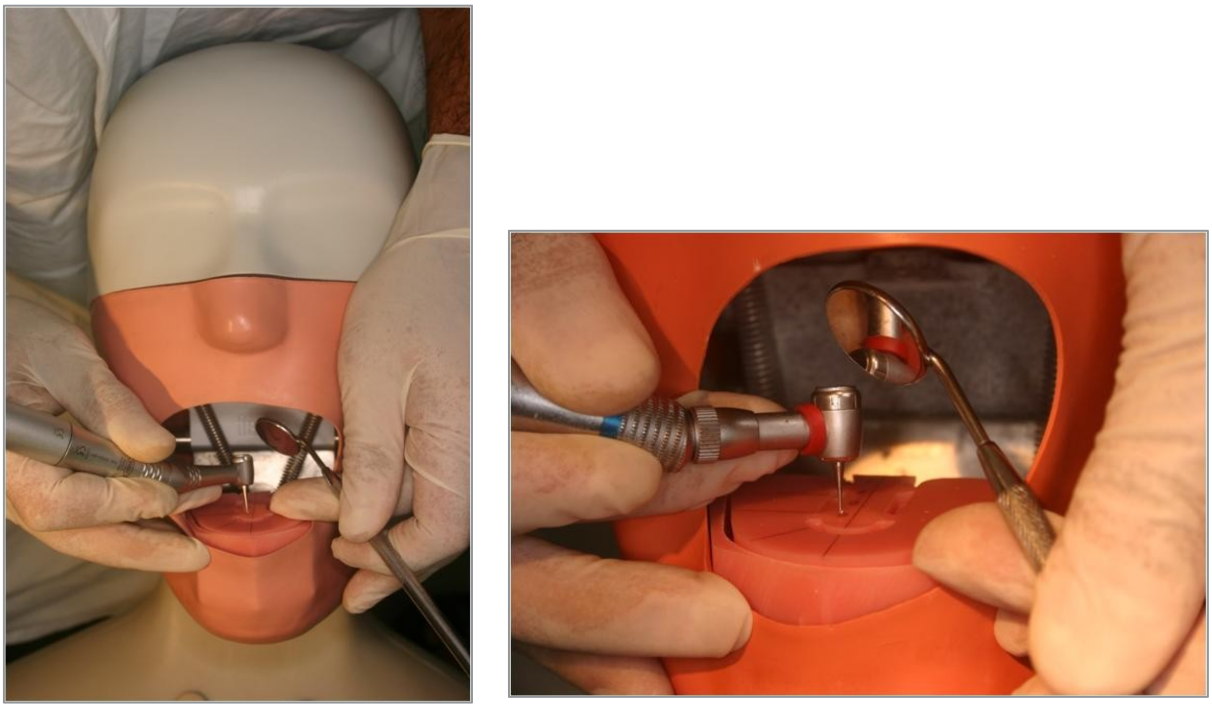
- Had discussions with Professor Richard Masters (Assistant Director – Research) and Dr Jamie Poolton (PhD fellowship) about possible future research collaborations
- Received comments and suggestions from Professor Bruce Abernethy (Director) about the current PhD research project.

Appendix 2 – Structure of the Adelaide Bachelor of Dental Surgery program (Mullins et al., 2003)

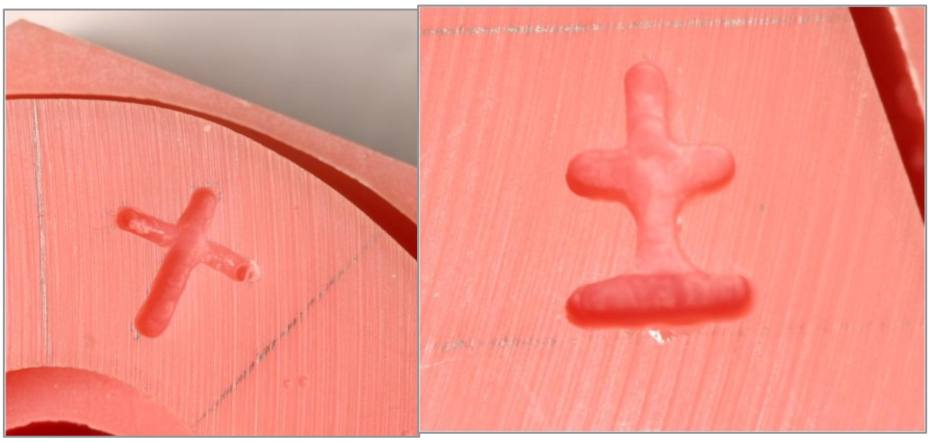


Note: *The current study involved students undertaking the Dental Clinical Practice 2 and 3 courses. These courses involved a range of learning activities related to operative dentistry (see Chapter 2, section 2.2)

Appendix 3 – Manual dexterity exercise



a) Students are required to perform exercises with a plastic block inserted into the Frasaco™ Phantom Head, as illustrated.



b) Examples of exercises requiring students to use a high speed rotary instrument to cut specific shapes

Appendix 4 – Dental Clinical Practice 2 (DCP 2) timetable in 2006 and 2008

Orientation week

Time	Monday	Tuesday	Wednesday	Thursday	Friday
9am - 12pm	Introduction to BDS 2	Dental Clinical Practice: class meeting	Dental Clinical Practice: class meeting	Self-directed learning	Dental Clinical Practice: class meeting
1 - 5pm	General Studies	Dental Clinical Practice: DPL part 1	Self-directed learning	Dental Clinical Practice: DPL part 2	Self-directed learning
5.30 - 8.30pm		Dental Clinical Practice: clinic	Dental Clinical Practice: clinic		

Semester 1

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>9 - 10am</td><td rowspan="3">Structure and function
or
Dental Health Science</td><td rowspan="2">Dental Clinical Practice: class meeting</td><td>Dental Health Science</td><td></td><td rowspan="2">General Studies</td></tr>
<tr><td>10 - 11am</td><td>Structure and Function</td><td rowspan="2">Structure and function</td></tr>
<tr><td>11am - 1pm</td><td></td><td></td><td></td></tr>
<tr><td>1.30 - 5pm</td><td>Self-directed learning</td><td>Dental Clinical Practice: laboratory (Group A)</td><td>Dental Clinical Practice: laboratory (Group B)</td><td>Dental Health Science</td><td>Dental Clinical Practice: laboratory (Group B)</td></tr>
<tr><td>5.30 - 8.30pm</td><td></td><td>Dental Clinical Practice: clinic (Group B)</td><td>Dental Clinical Practice: clinic (Group A)</td><td></td><td></td></tr>
</table>

Semester 2

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>9 - 10am</td><td></td><td rowspan="2">Dental Clinical Practice: class meeting</td><td rowspan="3">Self-directed learning</td><td rowspan="3">Structure and Function</td><td></td></tr>
<tr><td>10 - 11am</td><td rowspan="2">Structure and Function</td><td>Dental Health Science</td></tr>
<tr><td>11am - 1pm</td><td></td><td></td></tr>
<tr><td>1.30 - 5pm</td><td>Dental Health Science</td><td>Dental Clinical Practice: laboratory (Group A)</td><td>Dental Clinical Practice: laboratory (Group B)</td><td>Dental Health Science</td><td>Dental Clinical Practice: laboratory</td></tr>
<tr><td>5.30 - 8.30pm</td><td></td><td>Dental Clinical Practice: clinic (Group B)</td><td>Dental Clinical Practice: clinic (Group A)</td><td></td><td></td></tr>
</table>

Note: The class is divided into two groups of equal students: Group A and Group B.

Appendix 5 – Laboratory and clinic schedule: DCP 2 course in 2006 (Phase I)

Semester 1

WKS	LECTURES	CLINIC	SESS	LAB	DETAIL
0	INTRODUCTION TOOTH STRUCTURE BIOFILMS & CARIES GV BLACK CLASSIFICATION & NOMENCLATURE MI PHILOSOPHY - PREVENTIVE MI PHILOSOPHY - OPERATIVE				
1	DENT MATS - RESIN COMPOSITES		1	LAB ORIENTATION & INTRUMENTS	Including burs, matrix bands, etc Handpieces - Occupational Health & Safety - Cleaning & set procedures - D2 forms - Seating /posture
	- GLASS IONOMER CEMENTS	Clinic orientation. History. Exam Mandibular Arch. Diagnostic Tools	2	MANUAL DEXTERITY	Cutting lower blank Inserts in manikin
2	- AMALGAM	Examination Maxillary Arch. Diagnostic tools	1	MANUAL DEXTERITY	Cutting upper blank Inserts in manikin
	- SEALANTS, LINERS & BASES	Radiographs	2	MANUAL DEXTERITY	Lower Tooth Inserts
3	<u>SITE 1 LESIONS</u> - Fissure Management	Risk Assessment	1	CARIES REMOVAL (PLASTIC)	Lower Tooth Inserts
	- Large occlusals	Fluoride & Tooth Mousse	2	CARIES REMOVAL (PLASTIC)	Upper & Lower Tooth Inserts ("more practice")
4	<u>SITE 2 LESIONS</u> - Slot & Tunnel Preps	Complete Exam & TP (New Partners)	1 2	Fissure Exploration & F/S	47,46, 48 16, 17, 18
5	- Anterior Restorations	Alginate Impressions (Lower)	1 2	Sealant Restoration	36, 37, 38 16, 17, 18
6	- Incisal Edges	Alginate Impressions (upper)	1 2	Large Occlusal (CR)	47, 46, 48 16, 17, 18
7	ANZAC DAY	ANZAC DAY (No Clinic Wednesday)	2	Large Occlusal (Amalgam)	36, 26
8	- Cusp capping, pins & Bonded Ams	Rubber dam - Single tooth isolation)	1 2	Slot Prep (CR)	34 (D), 34 (M) 14 (M), 14(D)
9	<u>SITE 3 LESIONS</u> - Cervical lesions	Rubber dam - quadrant isolation	1 2	Slot with Occlusal (CR) (replace molars)	46 (MO), 47 (DO) 16 (MO), 17 (DO)
10	Perio Module 2 Perio Module 2	Plaque detection & removal OH Instruction	1 2	Slot with Occlusal (Am)	36 (MO), 37(DO) 26 (MO), 27 (DO)
11	Amalgam Debate	Supragingival calculus detection & removal Supra	1 2	Tunnel Prep	47 (M), 45 (D) 17 (M), 15 (D)
12	Selts & answering questions	Subgingival calculus detection & removal	1* 2	**Operative Technique (Lab test)** Test of Understanding (Written or Viva)	(To be advised) (To be advised)

Note: The number of exercises involving large occlusal, slot preparation and combination cavity preparations was less than semester 1 DCP 2 in 2008 (see Appendix 6). *The cavity preparation exercise used in this study was conducted in week 12, laboratory session 1.

SESS = sessions, CR = composite resin, Am = amalgam, D = distal surface, M = mesial surface, MO = mesio-occlusal surfaces and DO = disto-occlusal surface

Semester 2

WKS	LECTURES	CLINIC	SESS	LAB	DETAIL
1	Pain Control Resuscitation	Pain Control		Resuscitation Resuscitation	Practical Practical
2	Pain Control Pain Control	Pain Control	1 2	Cervical 3.1,3.2,3.3	GIC 34(B), 35(B) CR in enamel 43 (B) GIC 14 (B), 15 (B), 13 large (B) CR (cut back 13 & laminate
3	Perio Module 3 Perio Module 3	Pain Control	1 2	Large MOD Amalgam Cusp Protection (AM)	36 (MOD) Am 26 (MOD) Am 36 (MO) with MB cusp 26 (MOD) with DP cusp
4	Perio Module 3	Pain Control	1 2	Large MOD Amalgam Cusp Protection (CR)	46 (MOD) Am 16 (MOD) Am 46 (MOD) with MB Cusp 16 (MOD) with MP Cusp
5	RADIOGRAPHY Biological effects of ionising radiation Image quality - beam, exposure & film	PATIENTS	1 2	Cusp Replacement with pins (Bonded Am) Cusp Replacement with pins (Bonded Am)	37 MOD with MB and DB cusp 17 MOD with MP and MB cusp
6	RADIOGRAPHY Periapical paralleling technique Periapicals - interpretation 2nd sem workshop	PATIENTS	1 2	Ant tooth	GIC 41 (M), CR 31 (M) GIC 11 (M), CR 12 (M)
7	RADIOGRAPHY Panoramic radiography (Image production) Panoramic Radiography (anatomy)	PATIENTS	1 2	Ant tooth & Incisal edge	CR 21 MI), 22 (MI) CR 41 (MI), 42 (MI)
8	RADIOGRAPHY Panoramic radiography - good v/s bad Panoramic radiography - basic interpretation of dental and periodontal diseases only (no bony pathology nor TMJ)	PATIENTS	1 2	Incisal third	CR 11 (MID), 12 (MID) CR 31 (MID), 41 (MID)
9	Smoking Cessation	PATIENTS	1 2	RADIOGRAPHY	Examination of personal radiographic images
10	PSYCHO-SOCIAL ASPECTS OF PAIN	PATIENTS	1* 2	**Operative Technique (Lab test)**	**Lab exercise**
11	PSYCHO-SOCIAL ASPECTS OF PAIN	PATIENTS		Test of Understanding (Written or Viva)	
12	PSYCHO-SOCIAL ASPECTS OF PAIN	PATIENTS		TBA	

Note: Students completed the combination cavity preparation exercises on posterior teeth (week 3 – week 5) followed by cavity preparations on anterior teeth (week 6 – week 9). In contrast, in semester 2 in 2008, students initially completed cavity preparations on anterior teeth (week 3 – week 4), and then completed various exercises including the combination cavity preparation exercises based on a clinical scenario that was provided (week 5 – week 9) (see Appendix 6).

*The cavity preparation exercise used in this study was conducted in week 10, laboratory session 1.

CR = composite resin, Am = amalgam, GIC/GI = glass ionomer cement, D = distal surface, M = mesial surface, B = buccal surface, I = incisal surface, MO = mesio-occlusal surfaces, MOD = mesio-occluso-distal surface, MI = mesio-incisal surface and MID = mesio-inciso-distal surface

Appendix 6 – Laboratory and clinic schedule: DCP 2 course in 2008 (Phase II)

Semester 1

WKS	LECTURES	CLINIC	SESS	LAB	DETAIL
0	INTRODUCTION TO DCP 2 TOOTH STRUCTURE & PROPERTIES OF TEETH BIOFILMS & CARIES GV BLACK TOOTH CLASSIFICATION MINIMUM INTERVENTION PHYLOSOPHY (PREVENTIVE) MINIMUM INTERVENTION PHILOSOPHY (OPERATIVE)				
1	RESIN COMPOSITES GLASS IONOMER CEMENTS	Clinic orientation. History. Exam Mandibular Arch. Diagnostic Tools	1 2	LAB ORIENTATION & INTRUMENTS MANUAL DEXTERITY MANUAL DEXTERITY	
2	AMALGAM SEALANTS, LINERS & BASES	Examination Maxillary Arch. Diagnostic tools Radiographs	1 2	CARIES REMOVAL (tooth inserts) `	
3	SITE 1 LESIONS - Fissure Management - Preventive Resin Restoration (PRR) - Large occlusals	Risk Assessment Remineralising Treatments	1 2	RESTORING TOOTH INSERTS (GIC & CR) No Session 2 this week (good Friday)	
4	SITE 2 LESIONS - Slot & Tunnel Preps -	Complete Exam & TP (New Partners)	1 2	Fissure Management &Surface Protection Sealant Restoration (CR)	46,47,16,17,(48,18 surface protection) (36,37,26,27)
5	SITE 2 LESIONS - Anterior Restorations	Alginate Impressions (Lower)	1 [a, b] 2	**Occlusal (CR) GV black** Large Occlusal (CR) GV Black	**46,47,48** 16,17,18
6	SITE 3 LESIONS - Carious cervical lesions - Non Carious Cervical Lesions	Alginate Impressions (upper)	1 [a] 2	**Occlusal (Am) GV Black** Large Occlusal (Am) GV Black	**36,37,38** (26,27) - new, 18
	MIDSEMESTER BREAK			MIDSEMESTER BREAK	
7	COMPLEX RESTORATIONS - Cusp capping, pins & Bonded Amalgams	Rubber Dam - Single tooth isolation)	1 2	Polishing & finishing restorations SPEED TEST	
8	Perio Module 2 & 3 Perio Module 2 & 3	Rubber Dam - quadrant isolation	1 2	Slot Prep (CR)	34D,35D,45M 14MD,25MD
9	Perio Module 2 & 3 Perio Module 2 & 3	Plaque detection & removal OH Instruction	1 [a] 2	**Slot with Occlusal (CR) (replace molars) GV Black**	**46MO, 47MOD, 16MOD (Cavity preps only)** Restore Preps
10	Perio Module 2 & 3 Perio Module 2 & 3	Supra / Sub gingival calculus detection & removal	1 [a, b] 2	**Slot with Occlusal (Am) GV Black**	**36MO, 37MOD, 26MOD (cavity preps only)** Restore Preps
11	RADIOGRAPHY RADIOGRAPHY	Catch up session	1* 2	**Operative Technique (Lab test)** Slot Prep with Occlusal Extension - Am (GV Black)	Lab exercise, Large GV Black MOD 48MO, 17MOD (large GV Black Amalgams)
12	General Discussion General Discussion	Feedback	1 2	Tutor Feedback Tutor Feedback	

Note: *The cavity preparation exercise used in this study was conducted in week 11, laboratory session 1, [a]conducted an observational study and took photographs of cavity preparation, [b]collected critical incident reports

Semester 2

WKS	LECTURES	CLINIC	SESS	LAB	DETAIL
1	Pain Control Resuscitation (compulsory)	Pain Control		Resuscitation (compulsory) Lab exercises	SEE MY UNI FOR ROSTER for Tues pm & Fri pm (clin 1.3)
2	Pain Control Pain Control	Pain Control	1 2	Cervical Lesions (all margins in enamel) Cervical Lesions (gingival margin in dentine)	34B(GIC),35B(CR), 33B laminate 14B(GIC),15B (largeCR),13B (large laminate)
3	Behavioural Science Behavioural Science	Pain Control	1 2	Anterior tooth	12D(CR),11M(CR), 22M(GIC) 41D(CR),31M(CR), 32M(GIC)
4	Behavioural Science Behavioural Science	Pain Control	1 2	Anterior tooth & Incisal edge Incisal third, ie MID)	21MI(CR),22MI(CR) 11MID(CR),12MID (CR)
5	RADIOGRAPHY RADIOGRAPHY	PATIENTS	1 2	Patient Management	11, 13 fracture (2/3 crowns missing) CR 32, 31 fracture (2/3 crowns missing) CR 48 large MOD (box well into embrasures, occlusal width well up cusp inclines)
6	RADIOGRAPHY RADIOGRAPHY	PATIENTS	1 2	Patient Management	46 M, O & Resin F/s quadrant 4 21 M, D CR & Resin F/s quadrant 3 16 O PRR & Resin F/s quadrant 1 24 B Laminated, D slot CR & Resin F/s quadrant 2
7	RADIOGRAPHY RADIOGRAPHY	PATIENTS	1 2	Patient Management	21 MID CR, 22 MID CR 46 MOD Amalgam, 16 MOD Amalgam, 24 MOD CR
8	General Discussion General Discussion	PATIENTS	1[b] 2	**Patient Management**	**24 B Laminated, D slot** **16 O** 46 M, O 21 M, D
9	MIDSEMESTER BREAK DCP-2 EXAM	PATIENTS	1 2	MIDSEMESTER BREAK Patient Management	 21 MID, 22MID 46 MOD Amalgam, 16 MOD Amalgam, 24 MOD CR
10		PATIENTS	1 2	Patient Management	Practice session Practice session
11		PATIENTS	1* 2	**Operative Technique (Lab test)** Practice session	**Lab exercise** Practice session
12		Feedback	1 2	Feedback Feedback	Feedback Feedback

Note: Students completed cavity preparations on anterior teeth (week 3 – week 4) followed by various exercises including the combination cavity preparation exercises based on a clinical scenario that was provided (week 5 – week 9) (see Appendix 5 for differences in Phase I and II in the sequence of learning activities)

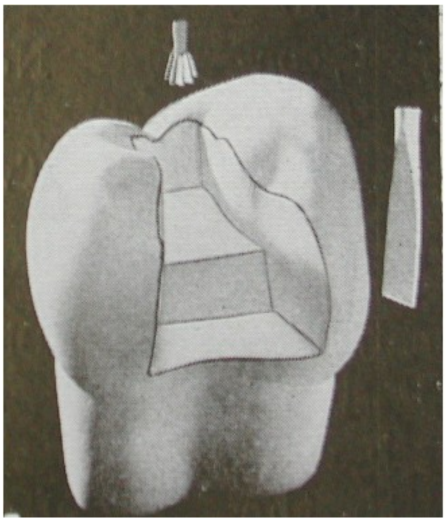
*The cavity preparation exercise used in this study was conducted in week 11, laboratory session 1, [b]collected critical incident reports

CR = composite resin, Am = amalgam, GIC/GI = glass ionomer cement, D = distal surface, M = mesial surface, B = buccal surface, I = incisal surface, MO = mesio-occlusal surfaces, MOD = mesio-occluso-distal surface, MI = mesio-incisal surface and MID = mesio-inciso-distal surface

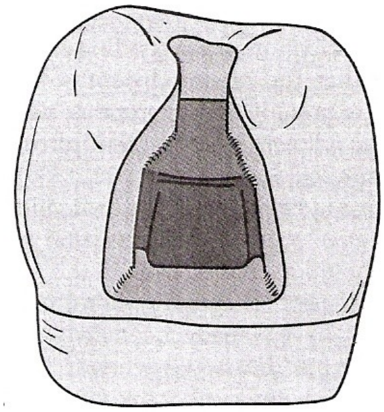
Appendix 7 – Self-assessment form for laboratory and clinic course (Wetherell et al., 1999)

Student Year level	Patient name & case note # Date
Please address ALL criteria: Knowledge Skills Patient management Professional behaviour	Procedure:
Student's comments	**Tutor's comments**
Strengths	
Areas needing improvement	
Strategies for improvement	
	Tutor's name & signature: ....

Appendix 8 – Examples of outline forms for an amalgam cavity preparation according to conventional GV Black and minimal intervention concepts



McGehee et al (1956)
Conventional GV Black's design



Roberson et al (2006)
Minimal intervention design

Appendix 9 – Dental Clinical Practice 3 (DCP 3) commencement term timetable in 2007

Week 1

<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td rowspan="2">9am - 12pm</td><td rowspan="2">Intro Lecture Dental Clinical Practice 3</td><td rowspan="2">Pain control: clinic</td><td>Dental Clinical Practice: laboratory</td><td>Dental Clinical Practice: laboratory</td><td>Dental Clinical Practice: laboratory</td></tr>
<tr><td>Dental Health Science/Clinic</td><td>Dental Health Science/Clinic</td><td>Dental Health Science/Clinic</td></tr>
<tr><td rowspan="2">1 - 5pm</td><td rowspan="2">Pain control: clinic</td><td rowspan="2">Pain control: clinic</td><td>Dental Clinical Practice: laboratory</td><td rowspan="2">Dental Health Science/Clinic</td><td rowspan="2">Dental Health Science/Clinic</td></tr>
<tr><td>Dental Health Science/Clinic</td></tr>
</table>

Week 2

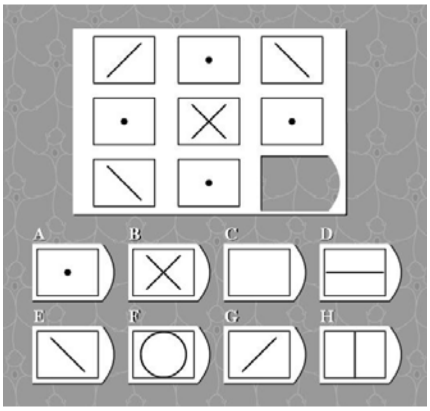
<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td rowspan="2">9am - 12pm</td><td rowspan="2">Dental Health Science/Clinic</td><td>Dental Clinical Practice: laboratory</td><td>Dental Clinical Practice: laboratory</td><td>Dental Clinical Practice: laboratory</td><td>Dental Clinical Practice: laboratory</td></tr>
<tr><td>Dental Health Science/Clinic</td><td>Dental Health Science/Clinic</td><td>Dental Health Science/Clinic</td><td>Dental Health Science/Clinic</td></tr>
<tr><td rowspan="2">1 - 5pm</td><td rowspan="2">Dental Health Science/Clinic</td><td rowspan="2">Dental Health Science/Clinic</td><td>Dental Clinical Practice: laboratory</td><td rowspan="2">Dental Health Science/Clinic</td><td rowspan="2">Dental Health Science/Clinic</td></tr>
<tr><td>Dental Health Science/Clinic</td></tr>
</table>

Week 3

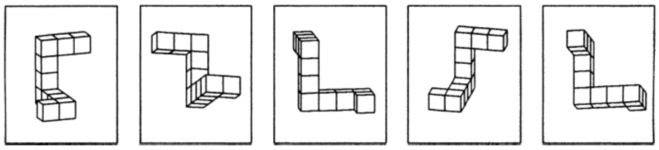
<table>
<tr><th>Time</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th><th>Friday</th></tr>
<tr><td>9am - 12pm</td><td>Dental Clinical Practice: endo</td><td>Dental Clinical Practice: laboratory</td><td>Dental Clinical Practice: laboratory</td><td>Laboratory exercise*</td><td>Laboratory exercise*</td></tr>
<tr><td rowspan="2">1 - 5pm</td><td rowspan="2">Dental Clinical Practice: endo</td><td rowspan="2">Dental Clinical Practice: endo</td><td>Dental Clinical Practice: laboratory</td><td rowspan="2">Dental Clinical Practice: endo</td><td rowspan="2">Dental Clinical Practice: endo</td></tr>
<tr><td>Dental Health Science/Clinic</td></tr>
</table>

Note: *The cavity preparation exercise was conducted with half of the class in each session.

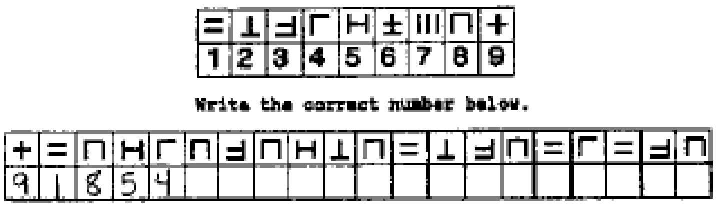
Appendix 10 – Examples of psychometric tests used in the current study



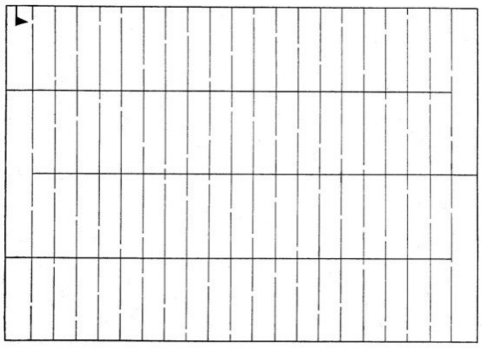
Raven's Advanced Progressive Matrices test



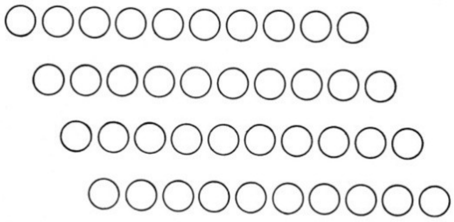
Mental Rotation test



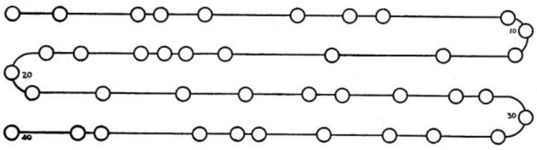
Symbol Digit Modalities test



Tracing subtest of MacQuarrie test



Tapping subtest of MacQuarrie test



Dotting subtest of MacQuarrie test

O'Connor Tweezer test

Appendix 11 – Written exercise

"Preparing you for the Clinic: Written Exercise"

Participation on this exercise forms part of the preclinical program.

This written exercise will take 20 mins in Total to complete.

Read scenario and answer Question 1- 4 20 mins

Scenario:

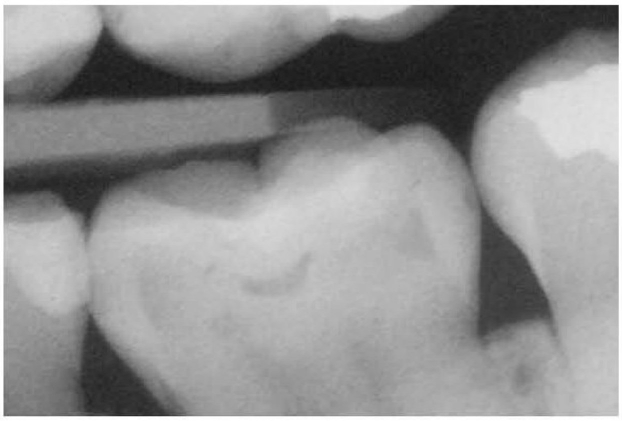
Mrs Smith is your patient for this afternoon. She is 40 year old part-time cleaner. She has had some previous dental treatment that included restorations (composite resin, amalgam and glass ionomer) and simple perio. She wants to keep her teeth. She has not been to a dentist for 2 yrs as she has been busy caring for an ill family member.

You completed an examination during the previous clinic session. You noted generalised moderate levels of gingivitis, supra- and subgingival plaque and calculus deposits on anterior teeth. Her mouth was well hydrated. Bitewing radiographs confirmed the findings of the clinical hard tissue examination that tooth 36 had primary carious lesions that require restoration (ie., they can not be remineralised) :

Today, you are going to manage tooth 36

Examine the radiographic image of tooth 36.

Tooth 36 MOD primary caries: Clinically there is occlusal caries and shadowing can be seen in the mesial and distal marginal ridge areas.



Scenario continued:

You review your clinical findings about Mrs Smith with your tutor and discuss the cavity prep and material choice for the tooth. With help from your tutor you discuss the options with Mrs Smith and come to a final decision to prepare the following:

Cavity Preparation: 36 – MOD cavity prep for amalgam

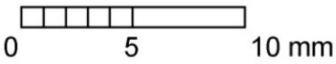
You will now prepare to cut the cavity prep as indicated above on your Frasaco tooth. Think of your Frasaco tooth as the real tooth situation. Imagine it has a carious lesion as presented in the scenario and the radiographic image.

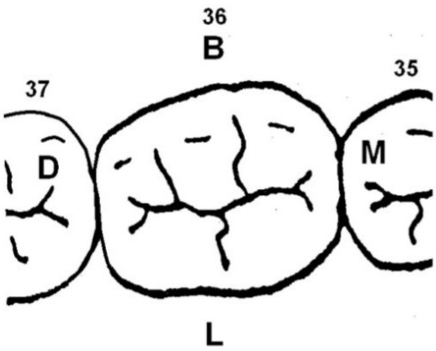
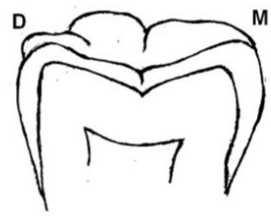
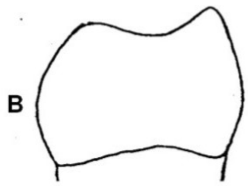
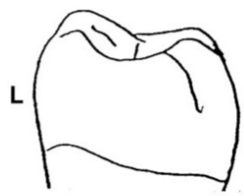
Question 1: What specific burs would you use to prepare the cavity preparation and discuss your reason(s) for your choice(s). **5 mins**

Type(s) of burs include name/size/type(s) of burs eg., beaver bur tungsten carbide high speed	**Reason(s) for choice** eg., for cutting enamel

Question 2:

On the labelled diagrams below (**occlusal, mesio-distal cross-sectional and proximal views**) draw the cavity design you will cut for the prep in your Frasaco tooth. **5 mins**



Occlusal view	**Mesio-distal cross-sectional view**
	
Mesial view	**Distal view**
	

Question 3: Discuss the rationale for your cavity design for the prep in your Frasaco tooth **5 mins**

………

………

………

Appendix 12 – Criteria for grading the written exercise

Question*	Outcome	Grade
1	Not all key burs and correct reasons are indicated	Unsatisfactory
	Three burs with correct supporting reasons are indicated.	Satisfactory
	Four burs with correct supporting reasons are indicated.	Good
2	• Outline is too wide/narrow or too deep corresponding to extension of caries indicated in the scenario • Proximal box does not include contact area • Sharp point outline • Cannot be corrected to be satisfactory	Unsatisfactory
	• Criteria for 'Unsatisfactory' but can be corrected to be satisfactory	Unsatisfactory Redeemable
	• Outline is appropriate corresponding to extension of caries indicated in scenario • Proximal box includes contact area with divergent form toward occlusal • Scale is not accurate	Satisfactory
	• Outline is appropriate corresponding to extension of caries indicated in scenario • Proximal box cover contact area with divergent form toward occlusal • Scale is accurate	Good
3	All key answers were indicated	
	• Isthmus width is at least 1/3 of bucco lingual width • Bucco-lingual wall of proximal box are at embrassure and flare to gingival area • Margin at proximal box is 90 degree • Proximal boxes and occlucal wall are tapered • Depth is at least 2 mm • No unsupported enamel	No. of correct answers >=3 'Satisfactory' No. of correct answers < 3 'Unsatisfactory'

*Note: Question 1 - discuss the specific burs needed to prepare the cavity
Question 2 - draw an outline of the cavity design on a diagram of the relevant tooth
Question 3 - discuss the rationale for the cavity design

Appendix 13 – Cutting burs used in cavity preparation exercises

Diamond cylindrical-shaped high-speed bur

Jet 330 Tungsten carbide high-speed bur

Appendix 14 – Examples of cavity preparation exercises completed by a second-year student in Semester 1 - 2008

Example in laboratory manual
for occlusal cavity

Example in laboratory manual
for mesio-occlusal cavity

Week 5
46, 47, 48 Occlusal
GV Black

Week 6
36, 37, 38 Occlusal
GV Black

Week 9
46MO, 47MOD
GV Black

Week 10
36MO, 37MOD
GV Black

Appendix 15 – Motivation survey

TASK EVALUATION QUESTIONNAIRE

The following items **concern your experience with this cavity preparation**. For each of the following statements, please indicate how true it is for you, using the following scale:

Statements	Not at all true			Somewhat true			Very true
1. I believe this activity could be of some value to me.	1	2	3	4	5	6	7
2r. I didn't feel nervous at all while doing this activity.	1	2	3	4	5	6	7
3. I put a lot of effort into this activity.	1	2	3	4	5	6	7
4. I believe doing this activity could be beneficial to me.	1	2	3	4	5	6	7
5r. I didn't try very hard to do well at this activity.	1	2	3	4	5	6	7
6. I felt pressured while doing this activity.	1	2	3	4	5	6	7
7. It was important to me to do well at this task.	1	2	3	4	5	6	7
8. I was anxious while working on this task	1	2	3	4	5	6	7
9. I would be willing to do this activity again because it has some value to me.	1	2	3	4	5	6	7
10. I tried very hard on this activity.	1	2	3	4	5	6	7
11. I think this is an important activity.	1	2	3	4	5	6	7
12r. I was very relaxed while doing this activity.	1	2	3	4	5	6	7
13. I think this activity is important to do because it can help me developing skills for preparing a cavity.	1	2	3	4	5	6	7
14r. I didn't put much energy into this activity.	1	2	3	4	5	6	7

Note: r = negatively worded statements

Appendix 16 – Observational protocol

Code:	Definitions
Cutting (C)	Time spent continuously cutting the teeth with the rotating bur
Observation (O)	Time spent without cutting but using a triplex syringe to clean the cavity, or a mirror to check the preparation, or obtaining and returning an instrument to the tray
Change of instrumentation (X)	Time spent changing instruments, for example, high speed/slow speed handpiece or hand instrument
Checking the preparation (I)	Time spent checking the preparation with a periodontal probe
Stopping (S)	Time spent without cutting but without putting the handpiece down, examining the preparation, or looking around.
-	Continuing that operation for 10 sec

Subject No……………
Recorded Time: …………………..

1	2	3	4	5	6	7	8	9	10

11	12	13	14	15	16	17	18	19	20

21	22	23	24	25	26	27	28	29	30

Appendix 17 – Retrospective think-aloud interview questions

No.	Questions
1	Before you started working, what were you thinking about?
2	Before you picked up the handpiece, what were you thinking about concerning your tooth preparation? **Follow-up questions:** If they talked about their plan… - Were these plans represented in your mind? - Were they visual or verbal? - In how much detail was this visualization? - Could you please explain more about the process that you use to achieve an acceptable cavity preparation?
3	During the cavity preparation, how did you judge whether what you were doing, was correct? **Followed up questions:** If they talk about criteria… - Which criteria did you use for this cavity preparation? - During the cavity preparation, what did you do to determine that your preparation had met that criterion?
4	During the cavity preparation, did you evaluate whether your final cavity preparation was satisfactory?
5	How much emphasis do you place on evaluating the cavity itself?
6	During the cavity preparation, how did you know that you were holding the hand piece correctly?
7	During the preparation, did you evaluate whether the relationship between the bur and tooth relationship was satisfactory?
8	How much emphasis did you place on evaluating the relationship between the bur and tooth?
9	Which do you think you evaluated more, the cavity preparation outcome or the bur-to-tooth relationship?
10	During the cavity preparation, how did you know that you were holding your instruments correctly, eg mouth mirror, spoon excavator?

Appendix 18 – Critical incident report form

***Dear second-year dental Student*:**
*This report is designed to gather data **on your learning experiences in the DCP II Laboratory sessions over the past few weeks**. It should take you approximately **<u>10 –15 minutes</u>** to complete. Thanks for your participation.*

Nattira Suksudaj

Student Name:……………………………………………………….……….Date:……………………

Please think back to one of your recent learning experiences from your DCP II laboratory sessions that "**stands out in your mind**".

1) briefly describe this experience, eg your experience may have been either **effective** or **ineffective for learning**.
   Please note: <u>what occurred</u> and <u>what you did in that situation.</u>

2) please indicate the context of the learning experience
   a) Week………… Afternoon or Evening (please underline or circle)
   b) Activity………………………………………….
   c) What discussions you had with your tutor:
      before the activity……………………………………………………………………………
      ……………………………………………………………………………………………………
      ……………………………………………………………………………………………………
   or during the activity……………………………………………………………………………
      ……………………………………………………………………………………………………
      ……………………………………………………………………………………………………
   or after the activity……………………………………………………………………………..
      ……………………………………………………………………………………………………
      ……………………………………………………………………………………………………

   d) factors/ issues that influenced the quality of your cavity preparation
      ……………………………………………………………………………………………………
      ……………………………………………………………………………………………………

3) explain why this experience has remained vivid in your mind,
   a) describe what your were thinking about as you were completing the exercise
   b) during the cavity preparation, what did you do to judge how you were going
   c) describe how you felt before, during and after the experience.

Appendix 19 – Sex differences in scores obtained for psychometric tests

Psychometric tests[a]	Unit	Third-year cohort					Second-year cohort				
		Sex[b]	**Mean**	**SD**	**Min**	**Max**	**Sex[d]**	**Mean**	**SD**	**Min**	**Max**
Raven's Advanced Progressive Matrices	score	Female	10.7	1.37	6.0	12.0	Female	11.3	0.9	8.0	12.0
		Male	10.8	1.43	7.0	12.0	Male	11.5	0.6	10.0	12.0
Mental Rotation test	score	Female	13.5	5.3	2.0	23.0	Female	11.7	4.5	4.0	23.0
		Male*	18.5	3.5	10.0	24.0	Male*	17.4	4.1	10.0	24.0
Symbol Digit Modalities	score	Female	70.5	10.1	46.0	93.0	Female	76.5	10.0	60.0	101.0
		Male	67.0	11.2	51.0	92.0	Male	72.2	14.3	54.0	108.0
Inspection Time test	millisecond	Female[c]	42.5	11.4	23.4	81.1	Female	43.5	9.6	24.8	63.3
		Male	44.8	11.0	30.3	77.0	Male	44.7	15.5	28.9	108.6
MacQuarrie test: Tracing	Score	Female	37.8	6.8	18.0	55.0	Female	36.3	6.7	18.0	47.0
		Male	34.0	7.6	19.0	50.0	Male	39.8	7.7	27.0	52.0

*p<0.05 (t-test), males outperformed females

SD = standard deviation, [a]data are normally distributed except scores on Raven's Advanced Progressive Matrices and O'Connor Tweezer tests

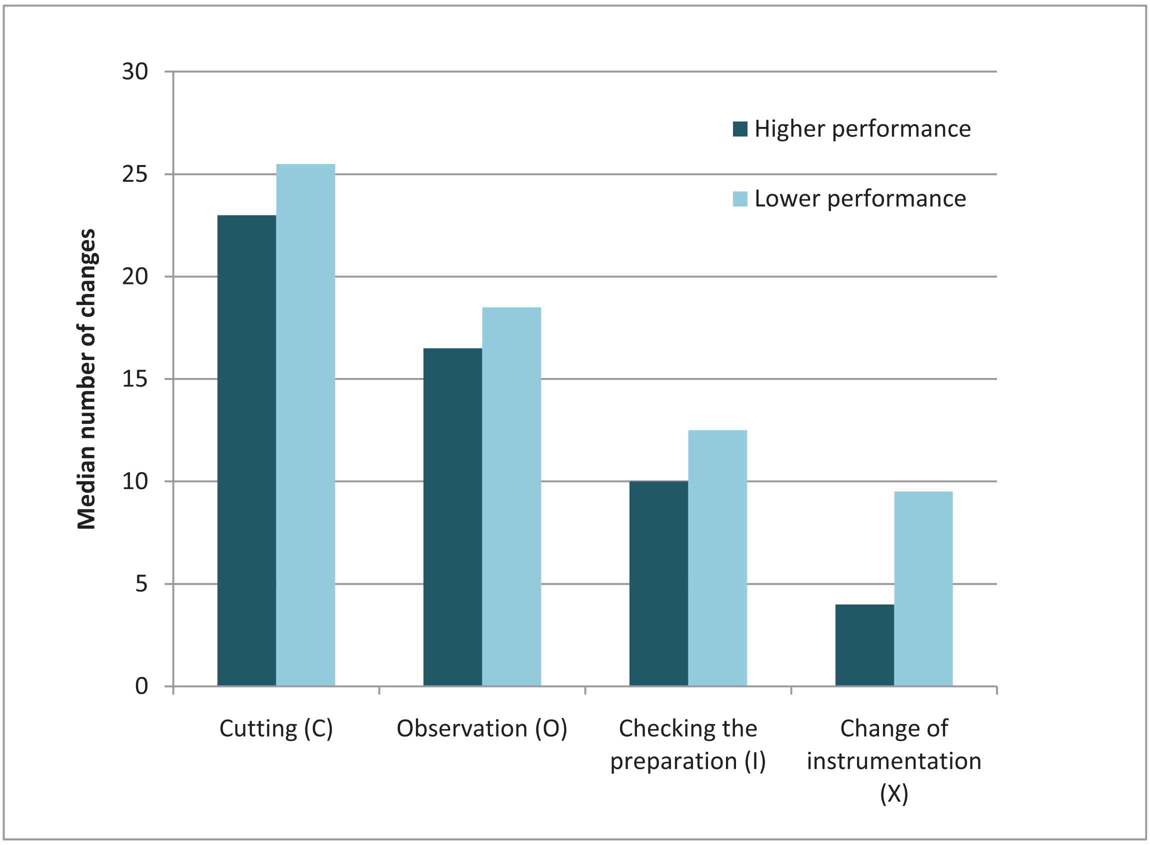
[b]female (n=41), male (n=33), [c]female (n=40), [d]female (n=28), male (n=25)

Sex differences in scores obtained for psychometric tests (con't)

Psychometric tests[a]	Unit	Sex[b]	Third-year cohort Mean	SD	Min	Max	Sex[d]	Second-year cohort Mean	SD	Min	Max
MacQuarrie test: Tapping	score	Female	50.6	6.7	36.0	66.0	Female	50.2	5.8	39.0	65.0
		Male	51.8	7.7	35.0	70.0	Male	51.1	8.6	30.0	69.0
MacQuarrie test: Dotting	score	Female	22.6	2.6	16.0	29.0	Female	22.8	3.7	15.0	31.0
		Male	21.4	2.9	13.0	28.0	Male	24.2	3.1	18.0	30.0
O'Connor Tweezer test	score	Female	5.6	1.1	4.1	9.3	Female	6.2	0.9	4.4	8.6
		Male	5.8	1.2	4.0	9.1	Male	6.4	1.5	4.5	9.4

SD = standard deviation, [a]data are normally distributed except scores on Raven's Advanced Progressive Matrices and O'Connor Tweezer tests
[b]female (n=41), male (n=33), [d]female (n=28), male (n=25)

Appendix 20 – Changes in operations during preparation of an MOD cavity with GV Black design in higher and lower performance sub-groups in the third-year cohort



Appendix 21 – Time spent on operations during preparation of an MOD cavity with GV Black design in higher and lower performance sub-groups in the third-year cohort