RMIT UNIVERSITY

Learning and Teaching Investment Fund final report

# Optimising experimental laboratory classes to maximise student learning outcomes


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15 February 2015


**Strategic objectives addressed:**

This project aligns with the following RMIT University values:

- **CREATIVE:** RMIT creates opportunities for students and staff to explore, test and fulfil their potential.
- **PASSIONATE:** Building enthusiasm and a sense of achievement in our students and staff is a high priority.
- **FAIR:** Learning opportunities support a diverse range of students, including those who may be disadvantaged.

This project addresses the following strategic priorities within *Strategic Goal 3 Connected*:

- **Priority 2** Strengthen RMIT partnership capability by focusing on: Developing capability in delivery of education, training and research with partners.
- **Priority 3** Ensure that all RMIT staff can support a connected and responsive University by developing policies, processes and professional development to: Support academics and teaching staff to deliver excellent education and research.
- **Priority 4** Establish a new industry practitioner role which will support practical education and training that is aligned to modern professional and industry needs and connects students and other staff to international industry and professional experience.

Further this project in aligns with the learning and teaching goals.

> *'We [RMIT University] expect and will support our academic and teaching staff to use new knowledge, educational techniques and technologies effectively, to understand the future needs of industry and the professions and requirements for international accreditation and recognition of our qualifications."*

**Internal order number: 360435**


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|---|---|---|
| **Funding scheme** | LTIF contestable | X |
| | Program Development Fund | |
| | RMIT Vietnam Program Development Fund | |

# 1 Executive summary

Education research has shown that laboratory classes are some of the least effective at producing positive student outcomes in terms of comprehension and long-term knowledge retention. There is also a very high cost associated with running laboratory classes that includes academic staff subject coordination, staff or postgraduate laboratory demonstrators, technical staff, chemicals and large demands upon university space. The usefulness of these learning environments has thus been questioned.

Given this high cost, the importance for professional accreditation, and our reputation as a hands-on practical training environment, it is important that this component of education is run as effectively as possible. This paper reports the evaluation of our current laboratory exercises, according to the Advancing Science by Enhancing Learning in the Laboratory (ASELL) survey instrument, which has been developed over some 15 years as part of a large national Australian study in the area of undergraduate laboratories. We have also introduced pre-laboratory online questions and quizzes, related to a few of the laboratory activities, that students are required to complete prior to attendance in laboratories. The students were surveyed both before and after the introduction of the online quizzes in order to establish if there was a relationship between student perceptions of the learning environment and the additional pre-laboratory preparation.

In this study we investigated the effectiveness of using online testing as preparation for the laboratory learning activity. Specifically, this study aimed to test the theory that we are at times exceeding the capacity of the working memory and that this causes students to disengage. Based upon the working memory model we aimed to re-distribute components of the laboratory educational experience into manageable activities, so that the students can focus on the core of each learning exercise. Limited evidence was found to support the hypothesis that the addition of pre-laboratory activities increases student perception of the overall laboratory experience.

# 2 Outcomes

As part of the project we surveyed students anonymously, who were completing the laboratory component of the first year chemistry course CHEM1031 ‘Chemistry of Materials 2’. We also surveyed the demonstrators (staff) teaching these laboratory classes. In total we collected 445 student surveys and 55 demonstrator surveys. A full data analysis was performed on the data collected from the staff and student responses in the surveys, allowing us to evaluate how the introduction of pre-lab exercises may have affected the student perceptions of the learning environment and the additional pre-laboratory preparation.

One of the key outcomes of the project was a set of pre-lab questions that were produced for the chemistry laboratory experiments that are part of the first year course CHEM1031 ‘Chemistry of Materials 2’. The exercises were written and created as a quiz within the Blackboard shell that all students can access. The tests comprised questions based on four key areas including equipment, procedure, safety and background theory and data analysis. The tests were created to be self-marking, allowing students to obtain instant feedback on how they answered the questions. Multiple attempts were allowed so that the students could achieve a required mark of 80% or greater. This was set as a pre-requisite for the students to commence the lab class. A hard copy of the questions was provided to students who were unable to complete the online quiz. These practical exercises are shared between a number of other courses in the School of Science, including: CHEM1030 ‘Chemistry of Materials 1’, CHEM1014 ‘Environmental Chemistry 1A Fundamentals’, CHEM1015 ‘Environmental Chemistry 1B Fundamentals’. The electronic version stored on Blackboard means that they are available for use in multiple courses and can be transferred easily.

### Student feedback

We maintained an excellent CES score for the course CHEM1031 which scored an OSI of 85.1% and having 167 student enrolments. We note that this score is reflective of the lecture as well as lab component but was within 1% of the OSI for the previous year indicating we retained the student satisfaction. Below is a summary of some of the comments made by students about the lab component of the 2015 'Chemistry of Materials 2' course, after implementation of the pre-lab exercises. These are taken from the CES Course Experience Survey and the Surveys conducted as part of the project.

| |
|---|
| Labs are relevant and they strongly reinforce the coursework. |
| The instructors for the labs are really friendly and very helpful throughout the lab work. |
| the lab sessions were really interesting. |
| The Labs as it shows hands on what is taught in the lectures |
| the practicals, …… to explain certain parts of the theory |
| Really less work to be done and the use of new equipments. |
| It wasn't too overwhelming and managed well with lab partner |
| Working in a pair with a clear goal and objective and everything went smoothly and achieved a great result. |

### Scholarly outputs

We are in the process of preparing a publication from the data collected in this project. We anticipate submitting this article to a peer reviewed journal in the field of chemistry education, such as the Journal of Chemical Education.

# 3 Project outcomes and impacts

## 3.1 Project outline – Introduction

Many academics who teach physical sciences believe that the laboratory is a key learning activity for developing subject-specific technical knowledge, as well as fostering scientific curiosity. In fact, laboratory-based classes are considered so central to the current educational model that it is common practice to apply academic hurdles to this component of the course. This is largely driven by the need to demonstrate competency, which is often necessary for professional accreditation. While laboratory classes fit with the pedagogical approach of active and experiential learning (Bodner, 1992; Sacks, 2005; Abdulwahed & Nagy, 2009), somewhat surprisingly, there is limited evidence to support the effectiveness of laboratory classes as learning activities (Johnstone *et al.* 1994). The most common criticism of the current model is that, in a laboratory session, we exceed the capacity of the 'working memory' that is typically only capable of processing 4-7 "chunks" of information (Johnstone, 1997; Taber, 2013). Therefore, exceeding the working memory will impact students' ability to engage and assimilate new knowledge. Therefore, we need to account for the working memory in the design and execution of laboratory classes.

Most academics that have taught practical classes have experienced 'overwhelmed' students who have disengaged from the practical exercise experience and are simply going through the motions. Laboratory classes are demanding and there are numerous new pieces of information that students must synthesize for successful completion as well as learning new physical skills. Based upon the working memory model it is possible that the expectations of what can be achieved in one class (theory, laboratory skills, data recording, data analysis as well as understanding scientific jargon) exceed what is reasonable (Johnstone *et al.*, 1994; Taber, 2013). The student becomes overwhelmed and focuses purely on the technical skills as a coping mechanism, thus failing to associate laboratory experience with a deeper understanding of the theoretical concepts (Llorens-Molina, 2008).

A common approach taken by educators is to increase the amount of work that students must complete prior to attending laboratory based learning activities (Llorens-Molina, 2008). Effective pre-laboratory preparation can enhance prerequisite knowledge and contextualize laboratory work in learning chemistry (Winberg & Berg, 2007; Llorens-Molina, 2008; Gregory & Trapani, 2012). Activities are designed to engage students and create a more scaffolded learning experience enabling students to have a more productive laboratory experience (Marissa Rollnick 2001; Gregory & Trapani, 2012). Pre-laboratory work may include a variety of activities, such as online quizzes, computer simulated exercises, making flow charts and concept maps. Online pre-laboratory exercises give students the flexibility to prepare in their own time and space, and are versatile and interactive to allow for real time feedback. It has been reported that there is a link between pre-laboratory activities and better conceptual understanding, autonomous behaviour and development of safety awareness amongst students (Winberg & Berg, 2007). While pre-laboratory exercises are standard in many practical classes, in this research, we also aim to assess student' perceptions of learning when the amount of preparation required is increased.

Read (2006) has posited that *'Laboratory classes should have education benefits for students who undertake them, and these benefits should be demonstrable'; and that:*

> *'careful consideration must be given to the laboratory as a learning environment if laboratory activities are to lead to meaningful outcomes'*.

The delivery and execution of chemistry laboratory classes at RMIT University have remained largely unchanged for some years. This may present a number of issues relating to the ease of delivery as demanded by cost-saving measures and rationalising, experienced by all higher education institutions (Ramsden, 1992). First year practicals often consist of fill-in-the-blanks pre-formatted laboratory reports that may have little educational value for the students, but are adopted due to ease of marking by laboratory demonstrators. In the worst-case scenario these learning activities could be viewed as surface learning and surface teaching conducted simply to satisfy professional accreditation. There is limited evidence to show the benefits of pre-laboratory activities in effective learning in the laboratory. According to Prince and Felder (2006) a laboratory experience that is relevant to the real world is often declared to be more motivating for students and matches the overarching education goals of this activity.

In this study we investigated the effectiveness of using online testing as preparation for the laboratory learning activity. Specifically, this study aimed to test the theory that we are at times exceeding the capacity of the working memory and that this causes students to disengage. Based upon the working memory model we wanted to re-distribute components of the laboratory education experience into manageable activities so that the students can focus on the core of each learning exercise.

## 3.2 Learning and Teaching

### 3.2.1 Academic learning

In the typical undergraduate education model there are three critical ingredients: (1) knowledge base/curriculum, (2) teacher, and (3) learner (Ramsden, 1992). The act of learning normally consists of a relationship between a *teacher* and a *learner*, where the teacher facilitates the assimilation of 'knowledge' or skills by the learner, referred to as *curriculum*. The concept of knowledge is not as static unchangeable facts, but rather aligns with the scientific principle of being contestable and defensible. A good working definition is that '*knowledge is true when it consists of statements that accurately correspond to or match what exists in the real world*' (Bodner, 1986). This definition means that knowledge is a changing view of reality that evolves through constant testing and evaluation. There are important parallels between societies view of 'knowledge' (i.e., continual feedback and contestable and continually evolving) and the process of learning. Specifically this is 'deep learning' - feedback processes for testing knowledge boundary and transformation of ones reality.

Learning focuses on the way in which people acquire new knowledge and skills and the way in which existing knowledge and skills are modified (Shuell, 1986). According to Shuell (1986) there are three attributes that define learning:

(a) a change in an individual's behaviour or ability to do something,

(b) a stipulation that this change must result from some sort of practice or experience, and

(c) a stipulation that the change is an enduring one.

There are different levels of learning that are referred to as surface or deep learning. The current ideology of education theorists is that 'deep learning' with 'understanding' is the key goal of the Australian and international higher education system (Ramsden, 1992). Specifically, the higher education system is driven by attempts to create experts and people who can emulate the thinking of those educating them. The development of knowledge specific expertise is obviously outside normal student expectations but it is reasonable to reflect upon what are key to this development. In our opinion to develop competence in an area of inquiry, students must:

1. Have a deep foundation of factual knowledge (surface learning)
2. Understand facts and ideas in the context of a conceptual framework, and
3. Organize knowledge in ways that facilitate retrieval and application (Bransford, 2000, p16).

It is a combination of 'surface learning' (i.e. facts, retrieval of information) combined with 'deep learning' (i.e. application, utilization) that is how most academics would define 'understanding' (Ramsden, 1992).

### 3.2.2 Teacher and learner relationship

The instructor-learner relationship is complex and hierarchical in nature. The instructor has been entrusted to assess the success in which students have assimilated the required body of knowledge. There are various models of teaching that define the teacher-learner relationship, however, the most commonly observed in the higher traditional education model, particularly in undergraduate classes is the teacher-centred model.

A discussion of quality teaching practice needs to reflect upon the goal and purpose of teaching. What is teaching? What is learning? What are we trying to achieve? It is obviously not possible to teach without students, but can students learn without teachers? The answer to this question is undoubtedly '*yes'* and is how 'knowledge' is indeed created. However, the vast majority of learning can only occur when facilitated by a teacher (i.e. lecture, book, video, quiz, YouTube) that may or may not involve personal interaction. Therefore, learning and teaching are inextricably linked, each with their own roles and responsibilities (See Table 1). According to Ramsden (1992, p9) teaching is '*defined to include the aims of the curriculum, the methods of transmitting the knowledge that those aims embody, the assessment of students, and the evaluation of the effectiveness of the instruction with which they are provided*'. However, '*teaching and learning are not synonymous; we can teach, and teach well, without having the students learn*' (Bodner, 1986). Similarly, we have all experienced the contrary, a poor learning situation where we learned despite the teacher. Indeed, at some point learners must take 'active' responsibility for their own learning and this lends itself to the 'constructivist' theory of learning. The teacher-student relationship works best when both parties 'engage' in the process, perform specific tasks assigned each role. Table 1 provides a summary of the responsibilities and process of learning.

| **Teacher** | **Learner** | |
|---|---|---|
| | **Stage 1 - Buy-In** | **Stage 2 - Assimilation** |
| 1. Evaluate the knowledge base<br>2. Decide on appropriate curriculum<br>3. Select learning objectives<br>4. Select learning activities to support learning objectives<br>5. Design formative and summative assessments based upon learning objectives | 1. Exposure to knowledge base from the engagement in a pre-defined process (i.e., listening to lectures, reading material, practical)<br>2. Respect and acceptance for learning process and those coordinating those activities/resources<br>3. Identification of known/unknown elements<br>4. Determining knowledge boundary | 1. Knowledge broken into manageable 'chunks' (if necessary) and may include elements of rote learning (viz., terminology).<br>2. Individual strategies developed for fitting pieces together<br>3. Incorporation of knowledge into world view<br>4. Transformation of perception of reality |

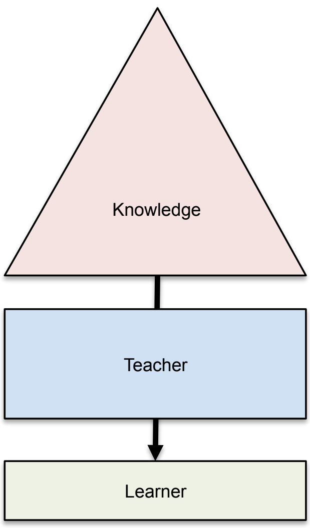
**Table 1. Key elements to learning – The process of learning based upon role**

The models of teaching can be thought of as according to three approaches, with a hierarchy of teaching skill reflected (Biggs, 1989). Model 1 is the teacher-centred approach and is the most common form of instruction present in universities throughout the world. In this model the teacher is considered the fount or gatekeeper of knowledge and that the students are 'passive' recipients to be filled with this discipline specific knowledge. This model allows teachers to take minimal responsibility for their actions and fulfilling their role as a good educator by placing the 'blame' of student learning outcomes on students. Phrases characteristic of this model include 'falling education standards', 'increasing the entrance requirements' (Ramsden, 1992). Using Model 1 a student may experience a quantitative change in knowledge but it is unlikely to facilitate change a in understanding (Biggs, 1989). Model 1 also implies that access to the 'knowledge' can only be achieved through the instructor, standing between the student and knowledge.

Model 2 (in our opinion) is a simplistic reaction to Model 1 in an attempt to create a student-centred learning environment. The underlying philosophy is that 'what the student does is actually more important to determining what is learned, than what the teacher does' (Shuell, 1986). The move from Model 1 - 'sage of the stage' to Model 2 'guide on the side' (McClanahan & McClanahan, 2002) could be more detrimental than the teacher-focused model, and devalue the contribution made by the instructor and the teacher, commonly referred to as 'tour guide' in this model. In this respect, the instructor is simply an observer of the knowledge base, similar to the student, and may or may not have the necessary fundamental knowledge expected of the student learners.

We have proposed an advancement of these models to Model 3 - Cooperative Teaching/ Learning that emphasizes the fact that teaching is a cooperative affair involving student and teacher, each with their own role and set of responsibilities. This model is based upon pedagogical practice, where the instructor develops appropriate content and learning activities that will facilitate learning and maximize the outcomes of learners. In this Model of education, the teacher and student both have equal access to the knowledge base and they share engagement to the knowledge base. Figure 1 provides a visual representation of the three education models. Model 3 will be used as the basis for an idealized education model for our approach.

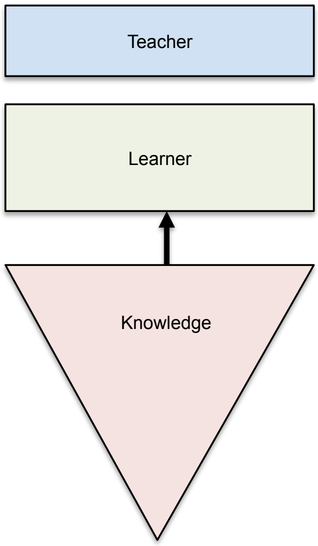
**Model 1 – Teacher Centered Approach to Learning**




*Teaching as the transmission of knowledge*

- Teaching is about transmitting knowledge from expert to students
- Student learning is separate from teaching
- Student learning is a process of acquiring new knowledge
- Problems in learning are not to do with the teacher.

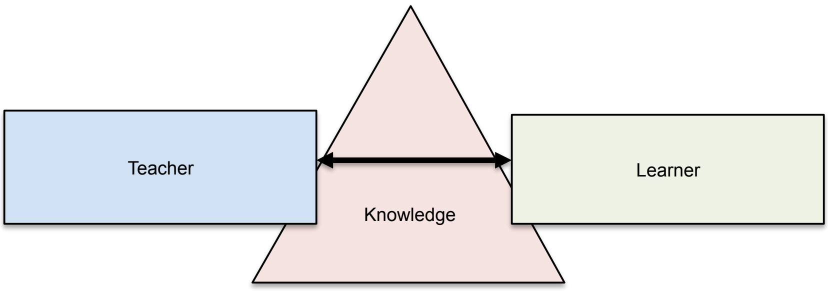
**Model 2 – Student Centered by Facilitating Activities**




*Teaching as the efficient orchestration of teaching skills*

- A shift from someone who "teaches" to someone who tries to facilitate learning; a shift from teaching by imposition to teaching by negotiation (Bodner, 1986)
- Teaching is about managing student activity
- Student learning is associated with teaching
- Problems in learning can be fixed by adopting the right teaching strategy.

**Model 3 – Cooperative Teaching/Learning**




*Teaching as the facilitation of learning*

- Teaching is about making it possible for students to learn subject content
- Teaching and student learning are parts of the same whole
- The activity of teaching and the process of reflecting are inextricably linked
- Feedback about learning continually monitored by teacher and corrections to learning activities made as necessary.

**Figure 1. Representations of different model of education from the teachers perceptive. Size of shape represents relative importance of teacher student. Access to knowledge has been included for perspective. Adapted from (Biggs, 1989; Ramsden, 1992)**

### 3.2.3 Teaching for effective learning

The goal of teaching is that the learner assimilates a subject specific body of knowledge with 'deep understanding' and with a high level of engagement. With this goal in mind a range of educational activities are selected to reach this desired outcome. In a normal situation, teachers will deliver lectures that have associated tutorials and in the case of chemistry, students will undertake practical work. The vehicle for determining the success of this process is through the assessment tasks. Good teaching facilitates the student's ability to assimilate subject knowledge matter but is also contingent upon 'good' learning. Cognitive approaches to learning stress that learning is an active, constructive, and goal-orientated process that is dependent upon the mental activities of the learner (Shuell, 1986). Good teaching should minimize those factors that lead to surface learning, and to maximize those leading to deep and achieving (Biggs, 1989).

The three main aspects of quality teaching that are considered the most important by learners are: (1) instructor knowledge base, (2) curriculum organization, and (3) instructor enthusiasm. According to Chickering and Gamson (1989) there are seven principles of good undergraduate teaching practice. These include:

1. Teacher-student contact
2. Cooperation among students
3. Active learning
4. Feedback (prompt)
5. Appropriate time to complete tasks
6. Teacher has and communicates high expectations
7. Respects diverse range of learners (Chickering & Gamson, 1989).

Good teaching narrows the gap between the ‘strong’ and ‘weak’ (Biggs, 2012). The teachers responsibility is to develop, stimulate and encourage students (Teixeira-Dias et al., 2005). Student explanations for poor lecturing include a non-responsive lecturer, a boring lecture, and a lecturer who doesn’t provide opportunities to ask questions (Uhari *et al.*, 2003). Students read their message of what is expected by the assessment tasks, and not by what the lecturer says (Biggs, 1989).

There is an increasing recognition that deep learning by students involves an understanding of their metacognitive processes. Researchers have shown that the fundamental difference between ‘strong’ and ‘weak’ students is self-awareness. This has led to development of the argument that good teaching is: *getting most students to use the higher cognitive level processes, that the more academic students use spontaneously*.

### 3.2.4 Models of learning – Surface, Deep and Achieving

Cognitive approaches to learning stress that learning is an active, constructive, and goal-orientated process that is dependent upon the mental activities of the learner (Shuell, 1986). Ultimately the responsibility for learning resides with the learner. If the learner chooses not to participate in learning activities or mentally engage with the knowledge, then it is unlikely that learning will occur. Constructivist framework states that meaning is not imposed or transmitted by direct instruction, but is created by the student’s learning activities (Biggs, 2012). Students undertake, or avoid, learning for a variety of reasons; those reasons determine how they go about their learning; and how they go about their learning will determine the quality of the outcome. This chain of events has implications for teaching (Biggs, 1989). Learning is cumulative in nature; nothing has meaning or is leaned in isolation (Shuell, 1986). The development of new knowledge is built on a foundation of previous experience and processed based on perceived notions and existing personal knowledge (Yager, 1991). According to Biggs (1989) the approach undertaken by learners will depend upon three factors:

- Presage – prior knowledge and experience
- Process - learning style and reaction to learning situation
- Product - learning outcome (Figure 2).

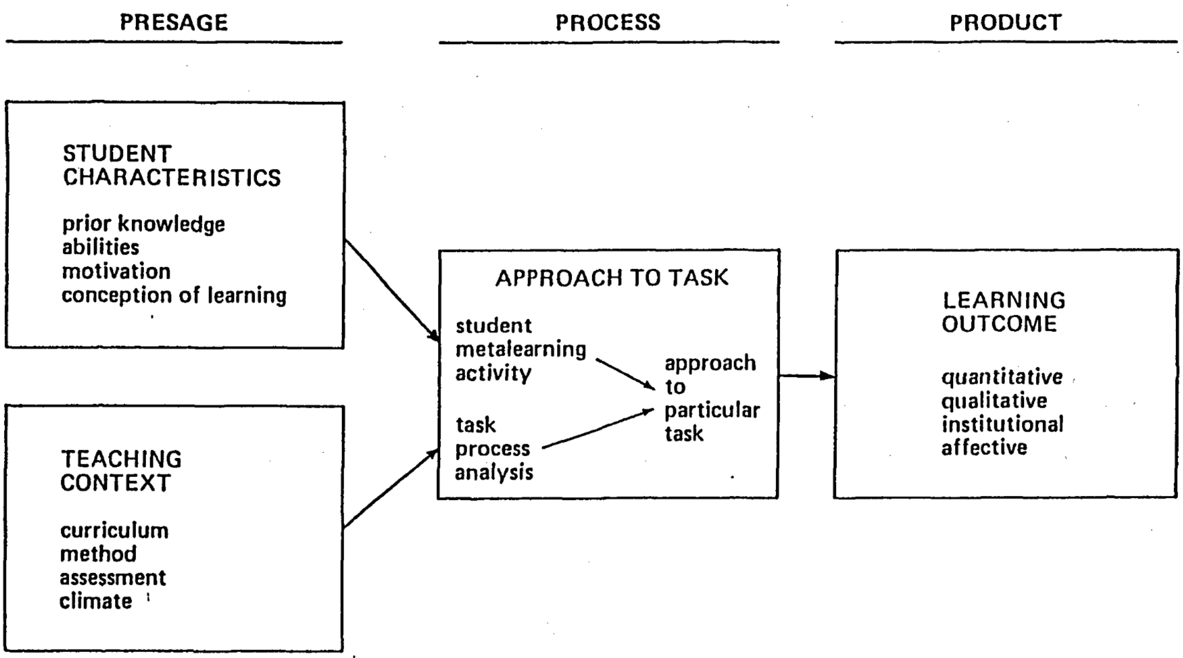



**Figure 2. Approach to learning (Biggs, 1989)**

Further, students have learning styles (surface, deep, achieving) that vary depending upon the individual's circumstance (Biggs, 1989). The approaches taken are often related to how much satisfaction students experience in their learning. Surface learning is an unsatisfying approach and can be the product of poor teaching or an individual student's dislike of a subject. According to Ramsden (1992) it is a mistake to think that surface and deep approaches to learning are in some way complementary or sequential. Learning is the 'approach' that the student chooses for specific learning activities and is not an inherent quality of the student (Ramsden, 1992). Stability across nations and age group leave little doubt as to the consistent nature of student learning. Deep approaches are related to higher quality outcomes and better grades. They are also more enjoyable. Surface approaches are dissatisfying; and they are associated with poorer outcomes (Ramsden, 1992).

| Approach | Motive | Strategy | Likely Outcome |
|---|---|---|---|
| Surface | Extrinsic: avoid failure but don't work very hard | Focus on selected details and reproduce accurately | Effective for recalling unrelated detail and frequently leads to low grades |
| Deep | Intrinsic: satisfy curiosity about topic | Maximize understandings: read widely, discuss, reflect | Leads to structural complex performances, which usually leads to high grades |
| Achieving | Achievement: complete for highest grade | Optimize organization of time and effort ("study skills") | Leads to high grades |

*Adapted from (Biggs, 1989)*

**Table 2. Typical approaches to learning**

The oppositional and hierarchical nature of deep and surface learning fails to recognize that in some instances rote learning or memorization is an essential component of the process (Mayer, 2002). Using the Bloom's taxonomy the education purpose is hierarchical in nature that moves from the lower level of 'remember' to the goal of 'create' (Table 3. Hierarchical structure of the cognitive process dimensions of the revised Bloom's Taxonomy). However, implied in this hierarchy is the mastery of each individual level before (or simultaneously) working on the next. For example, chemistry education has its own jargon 'remember' that must be mastered to participate in the education process and most certainly before the evaluate or create stage. However, teaching and assessing can be broadened beyond an exclusive focus on the cognitive process of 'remember' (Mayer, 2002).

| | | | | | |
|---|---|---|---|---|---|
| **Remember** | | | | | |
| *Recognizing* | **Understand** | | | | |
| *Recalling* | *Interpreting* | **Apply** | | | |
| | *Exemplifying* | *Executing* | **Analyze** | | |
| | *Classifying* | *Implementing* | *Differentiating* | **Evaluate** | |
| | *Summarizing* | | *Organizing* | *Checking* | **Create** |
| | *Inferring* | | *Attributing* | *Critiquing* | *Generating* |
| | *Comparing* | | | | *Planning* |
| | *Explaining* | | | | *Producing* |

**Table 3. Hierarchical structure of the cognitive process dimensions of the revised Bloom's Taxonomy**

Learning is a change in the memory of the student. Functionally, the human information processing system operates through three interactive memory systems – the sensory memory, the working memory, and the long-term memory (See Figure 3; Cantwell (2010)). Knowledge of information processing models could enhance their students' memory, knowledge, comprehension, and writing' (Matlin, 2002).' The working memory limited to about 7 (± 2) memory units remains constant (Miller, 1956), what constitutes a memory unit may change dramatically (Cantwell, 2010). As discipline specific knowledge is developed the 'memory unit' will expand with the memory capable of recognizing patterns allowing for further and deeper engagement with subject material.

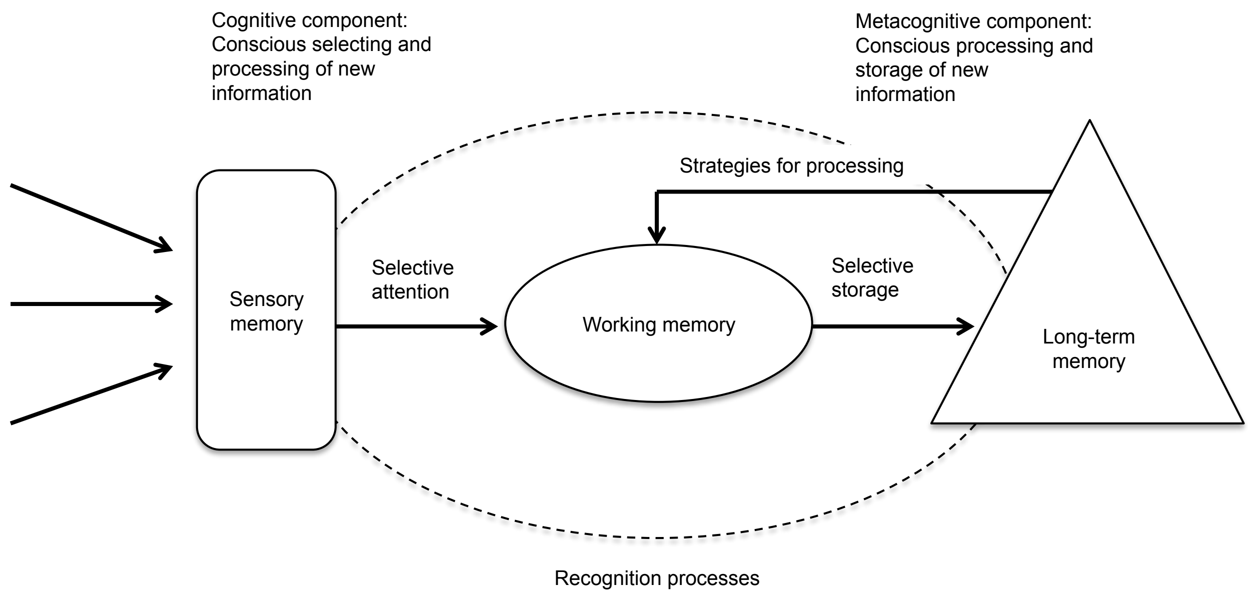



**Figure 3. Memory systems involved in learning; (Source: Cantwell (2010), page 28)**

The role of metacognition in students is now being shown to be important in the success of the students. Studies have demonstrated that students with a greater awareness of their own metacognitive process will have higher learning outcomes that those without. The role of metacognitive processes can include planning and setting goals/subgoals (Shuell, 1986).

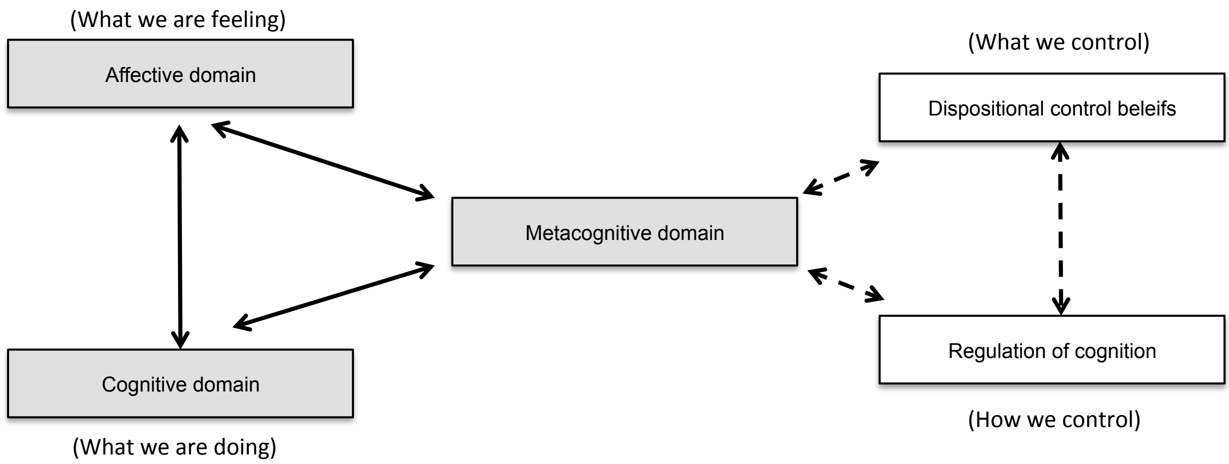



**Figure 4. Internal domains in learning; (Source: Cantwell (2010), page 26)**

## 3.3 Methodology

### 3.3.1 Study design

In order to understand the impact of pre-laboratory activities (specifically online tests) on student perceptions of the laboratory class, students were asked to complete an evaluation questionnaire following laboratory classes with and without compulsory pre-laboratory components. The pre-laboratory online quizzes, which were implemented as a compulsory, but non-assessable learning activity in the Chemistry of Materials 2 (CHEM1031) course. This is a year 1, second semester course for students majoring in Chemistry; students taking this course have normally completed Chemistry of Materials 1 (CHEM1030) in semester 1.

No changes were made to the practical component compared to previous years, and completion of a pre-laboratory exercise became a requirement for students to attend and participate in the practical learning activity. This took the form of an online set of questions that covered: the experimental design; methods; sequence of steps used during the experimental procedure: the use of equipment (included photographs and diagrams); laboratory safety aspects; and elements of the theory underlying the practical to be conducted. The questions were accessed as a quiz in Blackboard®, and comprised eleven to fourteen questions in various formats that are available using the Blackboard® quiz tool (for example, multiple choice, jumbled sentence, true / false). Students were allowed an unlimited number of attempts, however, they were required to gain a score of 80% or higher on each quiz in order to gain entry to the laboratory. If a student did not complete the quiz before the lab session, or did not achieve a score of ≥80%, they were provided with a paper copy of the quiz at the beginning of the lab session and were not allowed to start the lab until they had completed the quiz and achieved the required score.

At the conclusion of each laboratory class, students were invited to complete a voluntary hardcopy survey. The demonstrators were also asked to complete an anonymous, voluntary survey to determine the teaching staff's perception of student' learning with or without pre-lab work.

### 3.3.2 Experiments for evaluation

Four laboratory classes were evaluated for student and demonstrator opinion of the learning outcomes following completion of the practicals. An overview of the practicals is provided in Table 4.

| Number | Title | Pre-laboratory Exercise | Area | Description |
|---|---|---|---|---|
| 1 | The enthalpy of vapourisation of water | No | Physical | Students determine the vapor pressure of water as a function of temperature and used a graph based on the Clausius-Clapeyron equation to determine the enthalpy of vapourisation of water. |
| 2 | Reactions and tests of some organic functional groups | No | Organic | Students examine some typical reactions of alcohols, phenols and carbonyl compounds, with the focus of the experiment being reactions that could be used as functional group tests. |
| 3 | Some reactions and complexes of cobalt | Yes | Inorganic | Students prepare a complex of cobalt and investigate some reactions of cobalt and its complexes. |
| 4 | Chemical kinetics | Yes | Physical | Students determine the rate constant and order of a simple chemical reaction by monitoring the concentration of the reactant in the reaction over a period of time. |

**Table 4. Summary of the experiments used as part of the survey**

### 3.3.3 Survey design

The surveys used close-ended questions to compare learner and instructor perception of learning in the laboratory sessions. The responses were rated using a seven-point Likert rating scale from Strongly Disagree (1) to Strongly Agree (7). Open-ended questions were also used in the survey to encourage students and demonstrators to comment on the aspects that they found most enjoyable and interesting in the experiment. The survey was constructed in accordance with the Advancing Science by Enhancing Learning in the Laboratory (ASELL) laboratory evaluation template (ASELL, 2014). A series of questions were constructed to fit within four categories, which were (1) pre-laboratory preparation, (2) theory, (3) laboratory tasks, and (4) perception of experience. A summary of the questions asked according to category is listed in Table 5.

| Category | Questions | Description |
|---|---|---|
| Pre-laboratory preparation | • This experiment helped me to develop my chemistry knowledge<br>• I was prepared in this experiment and could concentrate on the chemistry theory<br>• I didn't feel organised during this experiment<br>• Pre-lab work prepared me for the steps required in the practical | This section investigated the amount of preparation put in by students before and after the use of pre-laboratory online quizzes. Preparation may involve completion of the online quizzes, review of the laboratory manual and discussions with other students. Organisation was an indication of the student's ability to effectively manage experimental tasks throughout the laboratory class. |
| Theory | • The lab manual provided clear background theory to aid my understanding<br>• I couldn't engage fully with the subject matter because there was too much to process<br>• There were too many requirements I had to follow while doing this experiment<br>• The experiment reinforced the background theory<br>• I was so confused in the laboratory that I ended up following the manual without linking what I was doing with the underlining theory<br>• I understood what I was doing in this experiment | Students were asked a series of questions about their knowledge and understanding of the scientific concepts presented to them during the laboratory sessions. These questions were used to assess the hypothesis that there is an association between poor learning outcomes and exceeding the capacity of the working memory that is limited to hold 7 (+/- 2) "chunks" of new information (Taber, 2013). |

| | | |
|---|---|---|
| Laboratory tasks | • I found the instructions in the lab manual clear<br>• I recorded my data onto the proforma without thinking about how to analyse it<br>• I had to clarify a lot of details with the demonstrator | These questions tested whether students were simply going through the motions during practicals or were able to plan ahead and think about how they would be analysing the recorded data post lab. The number of questions asked by students during the practical session was also monitored to help gauge their level of understanding of the experimental procedures and how well they could follow the written instructions in the lab manual. |
| Perception of experience | • I didn't learn anything from doing this experiment<br>• I felt overwhelmed while completing this experiment<br>• I enjoyed completing this experiment | This section gave an indication of student satisfaction and their learning experience through participation in the laboratory classes. These questions were used to help us assess whether there was too much required of the students during the practical, as well as to provide us with an indication of whether we needed to change other aspects of the practicals for future students. |

**Table 5. A list of survey questions divided into four categories.**

### 3.3.4 Participants

All students that were enrolled in the 2015 course CHEM1031 Chemistry of Materials 2 at RMIT University were included in this study. This is a first year chemistry course that runs in Semester 2 and the core first year chemistry course for students primarily doing the following degrees: Bachelor of Applied Science (BP229), Bachelor of Engineering (Chemical Engineering) (Honours) (BH079), Bachelor of Science (Applied Chemistry)/Bachelor of Engineering (Chemical Engineering) (Honours) (BH098) and Bachelor of Science (Nanotechnology)/Bachelor of Science (Applied Sciences) (BP247). It is expected that the students have completed VCE chemistry and will have completed the 1st semester chemistry course (CHEM1030 Chemistry of Materials 1). Students are allocated four, three-hour laboratory sessions, over a four-week period. The laboratory classes run in two cycles to accommodate the large cohort of students. The four-week lab program is run in weeks 5-8 and repeated in weeks 9-12 of the semester. The separation of cohorts may impact the survey results due to alignment of the theory components that may not have been completed by cohort 1 when they attempted the laboratory section.

The four practical classes were run twice during the semester for different groups of students, running from weeks 5-8 and weeks 9-12, and students and demonstrators were surveyed from both groups. Cohort 1 consisted of 63 students and the number of respondents ranged from 36-58, representing 63-92% of the student cohort. Cohort 2 consisted of 97 students, from which 60-70 students responded, representing 63-74% of the cohort. A summary of the number of student and demonstrator participants is provided in Table 6.

| Week | Students | | Demonstrators | | Cohort |
|---|---|---|---|---|---|
| | Attended | Responded (%) | Attended | Responded (%) | |
| 1 | 63 | 58 (92%) | 6 | 5 (83%) | Cohort 1 |
| 2 | 57 | 36 (63%) | 6 | 6 (100%) | |
| 3 | 57 | 43 (75%) | 6 | 6 (100%) | |
| 4 | 61 | 47 (77%) | 6 | 6 (100%) | |
| 5 | 95 | 70 (74%) | 8 | 8 (100%) | Cohort 2 |
| 6 | 96 | 60 (63%) | 8 | 8 (100%) | |
| 7 | 97 | 66 (68%) | 8 | 8 (100%) | |
| 8 | 95 | 65 (68%) | 8 | 8 (100%) | |

**Table 6. Summary of student survey participants**

### 3.3.5 Data analysis

Analysis was completed using the statistical software packages Mintab 17™ and SPSS.

## 3.4 Results and discussion

### 3.4.1 Overall

The first test undertaken was to determine if there was a difference in response based upon the Cohort. This statistical analysis was conducted using both *one-way analysis of variance (ANOVA)*, and *Cross-tabulation and Chi-square analysis* for each question. The ANOVA treats the numeric response as a continuous variable, and compares the mean and spread of data from each category, while, cross tabulation and chi-square analysis treats responses as categorical variables (i.e., either 1 or 2), and is used to determine whether the variables are associated or independent. There is some debate about the most appropriate technique for analysing data generated using Likert scale data, thus both types of analysis were performed when examining differences. In most instances both techniques produced very similar results, with the exception of two questions in experiment 2 (Reactions and tests of some organic functional groups). For this experiment, both tests indicated no statistically significant difference on comparison of the overall impact of Cohort with question response (i.e., $p > 0.05$). This may, however, be due to the relative timing of the experiments and the associated theory component, where the latter was delivered after Cohort 1 had completed their experimental work. The entire database of results can be found in the Supplementary Information section. Given that both statistical tests indicated no difference on comparison of Cohort, this category was eliminated from further interrogation.

There were sixteen closed and two open questions that examined the students' perception of each practical session. The overall descriptive statistics for each question is presented in Table 7. Included in the summary statistics are the number of respondents (N), the number of missing responses (N*), and the mean, median and standard deviation (StDev). For all questions, the responses ranged from Strongly Disagree (1) to Strongly Agree (7). The standard deviation was less than 1.8 for all Likert Scale questions, indicating that students have responded in a similar manner to all questions, regardless of practical, cohort, or pre-laboratory exercise. This also implies that differences in responses are likely to be slight.

| Variable | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|
| This experiment helped me to develop my chemistry knowledge (q12) | 427 | 18 | 5.49 | 6.00 | 1.22 |
| I was prepared in this experiment and could concentrate on the chemistry theory (q8) | 437 | 8 | 5.21 | 5.00 | 1.30 |
| I didn't feel organised during this experiment (q9) | 440 | 5 | 2.53 | 2.00 | 1.43 |
| Pre-lab work prepared me for the steps required in the practical (q14) | 425 | 20 | 4.94 | 5.00 | 1.45 |
| The lab manual provided clear background theory to aid my understanding (q5) | 439 | 6 | 5.45 | 6.00 | 1.26 |
| I couldn't engage fully with the subject matter because there was too much to process (q16) | 428 | 17 | 2.56 | 2.00 | 1.48 |
| There were too many requirements I had to follow while doing this experiment (q13) | 425 | 20 | 2.79 | 2.00 | 1.51 |
| The experiment reinforced the background theory (q11) | 428 | 17 | 5.45 | 6.00 | 1.24 |
| I was so confused in the laboratory that I ended up following the manual without linking what I was doing with the underlining theory (q6) | 441 | 4 | 2.45 | 2.00 | 1.41 |
| I understood what I was doing in this experiment (q10) | 442 | 3 | 5.68 | 6.00 | 1.17 |
| I found the instructions in the lab manual clear (q15) | 426 | 19 | 5.59 | 6.00 | 1.31 |
| I recorded my data onto the proforma without thinking about how to analyse it (q1) | 441 | 4 | 3.21 | 3.00 | 1.71 |
| I had to clarify a lot of details with the demonstrator (q4) | 435 | 19 | 3.27 | 3.00 | 1.59 |
| I found the instructions in the lab manual clear (q15) | 426 | 19 | 5.59 | 6.00 | 1.31 |

| | | | | | |
|---|---|---|---|---|---|
| I recorded my data onto the proforma without thinking about how to analyse it (q1) | 441 | 4 | 3.21 | 3.00 | 1.71 |
| I had to clarify a lot of details with the demonstrator (q4) | 435 | 19 | 3.27 | 3.00 | 1.59 |
| How many hours did you spend preparing for this experiment (including pre-lab if applicable)? (q17) | 404 | 41 | 1.29 | 1.00 | 1.74 |
| How many times did you ask your demonstrator for clarification? (q18) | 388 | 57 | 3.23 | 3.00 | 3.36 |

**Table 7. Descriptive statistics for pre-laboratory preparation themed questions according to experiment**

To ease the interpretation of our findings the results will be discussed by theme.

### 3.4.2 Pre-laboratory preparation

There were four closed and two open questions that examined the students' perception of the impact of their pre-laboratory on their performance in the practical session. One-way ANOVA and Cross tabulation/Chi-square analysis were performed for each question and compared to the categorical variables: (1) practical, (2) pre-lab, and (3) gender. Differences that were statistically significantly different ($p < 0.05$) are shown in red (Table 8).

| | **ANOVA** | | | **Cross square chi-square analysis** | | |
|---|---|---|---|---|---|---|
| | **Practical** | **Prelab** | **Gender** | **Practical** | **Prelab** | **Gender** |
| This experiment helped me to develop my chemistry knowledge (q12) | 0.755 | 0.375 | <0.001 | 0.468 | 0.552 | 0.008 |
| I was prepared in this experiment and could concentrate on the chemistry theory (q8) | 0.151 | 0.085 | 0.032 | 0.328 | 0.283 | 0.046 |
| I didn't feel organised during this experiment (q9) | 0.083 | 0.662 | <0.001 | 0.149 | 0.333 | <0.001 |
| Pre-lab work prepared me for the steps required in the practical (q14) | <0.001 | <0.001 | 0.001 | <0.001 | <0.001 | 0.017 |
| How many hours did you spend preparing for this experiment (including pre-lab if applicable)? | 0.001 | <0.001 | 0.313 | NA | NA | NA |
| How many times did you ask your demonstrator for clarification? | <0.001 | 0.139 | 0.136 | NA | NA | NA |

**Table 8. Analysis of difference in response for each questions based upon the categorical variables practicals, pre-laboratory work (prelab) and c) gender using on-way ANOVA (Minitab™) and Crosstabs and chi-square analysis (SPSS™).**

The descriptive statistics for each question, broken down by experiment, are presented in Table 9, and include the overall summary statistics for comparison. In general, the students agreed that: the experiment helped to develop their chemistry knowledge (Overall mean 5.49; Range 5.39-5.54); that they were prepared for the experiment and could concentrate on the underlying theory (Overall mean 5.21; Range 4.98-5.40); and that the pre-laboratory work prepared them for the practical steps requiring completion (Overall mean 4.94; Range 4.43-5.41). They slightly disagreed with the statement 'I didn't feel organised during this experiment' (Overall mean 2.53; Range 2.34-2.71).

| Variable | Prac | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| This experiment helped me to develop my chemistry knowledge (q12) | Overall | 427 | 18 | 5.49 | 6.00 | 1.22 |
| | Cobalt | 104 | 5 | 5.55 | 6.00 | 1.30 |
| | Enthalpy | 120 | 8 | 5.39 | 5.00 | 1.23 |
| | Kinetics | 111 | 1 | 5.54 | 6.00 | 1.10 |
| | Organic Functional Group | 92 | 4 | 5.50 | 6.00 | 1.30 |
| I was prepared in this experiment and could concentrate on the chemistry theory (q8) | Overall | 437 | 8 | 5.21 | 5.00 | 1.30 |
| | Cobalt | 105 | 4 | 5.40 | 6.00 | 1.19 |
| | Enthalpy | 127 | 1 | 5.20 | 6.00 | 1.39 |
| | Kinetics | 112 | 0 | 5.24 | 5.50 | 1.27 |
| | Organic Functional Group | 93 | 3 | 4.98 | 5.00 | 1.29 |
| I didn't feel organised during this experiment (q9) | Overall | 440 | 5 | 2.53 | 2.00 | 1.43 |
| | Cobalt | 108 | 1 | 2.42 | 2.00 | 1.36 |
| | Enthalpy | 128 | 0 | 2.34 | 2.00 | 1.38 |
| | Kinetics | 110 | 2 | 2.71 | 2.00 | 1.58 |
| | Organic Functional Group | 94 | 2 | 2.73 | 2.00 | 1.38 |
| Pre-lab work prepared me for the steps required in the practical (q14) | Overall | 425 | 20 | 4.94 | 5.00 | 1.45 |
| | Cobalt | 105 | 4 | 5.41 | 6.00 | 1.46 |
| | Enthalpy | 118 | 10 | 4.72 | 4.50 | 1.29 |
| | Kinetics | 111 | 1 | 5.14 | 5.00 | 1.55 |
| | Organic Functional Group | 91 | 5 | 4.43 | 4.00 | 1.32 |
| How many hours did you spend preparing for this experiment (including pre-lab if applicable)? | Overall | 404 | 41 | 1.29 | 1.00 | 1.74 |
| | Cobalt | 101 | 8 | 1.80 | 1.00 | 3.00 |
| | Enthalpy | 117 | 11 | 0.99 | 1.00 | 0.85 |
| | Kinetics | 102 | 10 | 1.38 | 1.00 | 0.98 |
| | Organic Functional Group | 84 | 12 | 0.98 | 1.00 | 1.02 |
| How many times did you ask your demonstrator for clarification? | Overall | 388 | 57 | 3.23 | 3.00 | 3.36 |
| | Cobalt | 100 | 9 | 3.46 | 3.00 | 2.60 |
| | Enthalpy | 110 | 18 | 2.69 | 2.00 | 1.95 |
| | Kinetics | 98 | 14 | 2.50 | 2.00 | 2.56 |
| | Organic Functional Group | 80 | 16 | 4.59 | 3.00 | 5.51 |

**Table 9. Descriptive statistics for pre-laboratory preparation themed questions according to experiment; significant differences marked red**

Question 14 (*Pre-lab work prepared me for the steps required in the practical)* yielded a statistically significant difference ($p < 0.05$ level) for all categories (*M ranges from 4.43-5.41*), using both statistical techniques. There was also a significant difference between question 14 and the variables: b) prelab (*M ranges from 4.59-5.27*) and c) gender (*M ranges from 4.59-5.24*) (Table 9). This was expected as only two of the four practicals contained compulsory pre-laboratory work.

Examination of differences based upon pre-laboratory activity indicate differences in response based upon the amount of time required to prepare, and general improvements in the learning experience (Table 10). Given that the students were expected to complete pre-laboratory work as part of this study, it was expected that they would provide a larger estimate of the time required to prepare for the experiment. Based upon the results of this section of the survey it appears that the pre-laboratory component is not associated with students feeling more prepared for their laboratory classes. It was found that the pre-laboratory requirements increased the mean time invested in preparation from 0.98 to 1.59 hours and was statistically significantly different ($p < 0.001$).

While not statistically significantly different in itself ($p = 0.139$), the mean number of questions from students to demonstrators decreased from 3.49, with no pre-laboratory activity, to 2.99 when doing pre-laboratory work. This finding somewhat supports that additional pre-laboratory work improves student performance in the laboratory. But, surprisingly, though it was expected that the students would feel different about the experiment based upon the level of pre-laboratory activity and engagement this was not supported by the data.

| Variable | Prelab | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| This experiment helped me to develop my chemistry knowledge (q12) | No | 212 | 12 | 5.44 | 6 | 1.25 |
| | Yes | 215 | 6 | 5.54 | 6 | 1.20 |
| I was prepared in this experiment and could concentrate on the chemistry theory (q8) | No | 220 | 4 | 5.10 | 5 | 1.35 |
| | Yes | 217 | 4 | 5.32 | 6 | 1.23 |
| I didn't feel organised during this experiment (q9) | No | 222 | 2 | 2.50 | 2 | 1.39 |
| | Yes | 218 | 3 | 2.56 | 2 | 1.48 |
| Pre-lab work prepared me for the steps required in the practical (q14) | No | 209 | 15 | 4.59 | 4 | 1.31 |
| | Yes | 216 | 5 | 5.27 | 5.5 | 1.51 |
| How many hours did you spend preparing for this experiment (including pre-lab if applicable)? | No | 201 | 23 | 0.98 | 1 | 0.91 |
| | Yes | 203 | 18 | 1.59 | 1 | 2.23 |
| How many times did you ask your demonstrator for clarification? | No | 190 | 34 | 3.49 | 3 | 3.97 |
| | Yes | 198 | 23 | 2.99 | 2 | 2.62 |

**Table 10. Descriptive statistics for pre-laboratory preparation themed questions according to pre-laboratory activity; significant differences marked red**

The summary statistics based upon gender are presented in Table 11. Given that gender may not be considered simply a male/female dichotomy, this identity was left open to participants to self-describe, and resulted in three categories of male, female and unassigned (normally without description on the survey). The differences in response are marginal, and the difference in responses based upon gender did not alter the overall conclusion. For example, the mean male-female response were not opposites. Rather it appears that female students tend to be more definitive in their responses i.e. in the positive or negative direction, as opposed to more neutral. Also, of note is that gender did not appear to impact the amount of time preparing for the laboratory class or the number of questions asked of the demonstrators.

| Variable | Gender | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| This experiment helped me to develop my chemistry knowledge (q12) | NA | 18 | 2 | 5.28 | 5 | 1.02 |
| | F | 156 | 4 | 5.80 | 6 | 1.06 |
| | M | 253 | 12 | 5.31 | 6 | 1.30 |
| I was prepared in this experiment and could concentrate on the chemistry theory (q8) | NA | 20 | 0 | 4.40 | 4.5 | 1.39 |
| | F | 156 | 4 | 5.42 | 6 | 1.30 |
| | M | 261 | 4 | 5.15 | 5 | 1.26 |
| I didn't feel organised during this experiment (q9) | NA | 19 | 1 | 3.31 | 3 | 1.53 |
| | F | 157 | 3 | 2.15 | 2 | 1.35 |
| | M | 264 | 1 | 2.70 | 2 | 1.42 |
| Pre-lab work prepared me for the steps required in the practical (q14) | NA | 17 | 3 | 4.60 | 5 | 1.42 |
| | F | 157 | 3 | 5.24 | 5 | 1.43 |
| | M | 251 | 14 | 4.76 | 5 | 1.44 |
| How many hours did you spend preparing for this experiment (including pre-lab if applicable)? | NA | 16 | 4 | 2.89 | 1 | 7.29 |
| | F | 150 | 10 | 1.16 | 1 | 0.92 |
| | M | 238 | 27 | 1.26 | 1 | 1.019 |
| How many times did you ask your demonstrator for clarification? | NA | 16 | 4 | 6.31 | 11.13 | 3.50 |
| | F | 142 | 18 | 2.85 | 2 | 2.38 |
| | M | 230 | 35 | 3.25 | 3 | 2.58 |

**Table 11. Descriptive statistics for pre-laboratory preparation themed questions according to gender; significant differences marked red**

### 3.4.3 Theory

There were six closed questions included in the student survey, and analysis of difference using ANOVA and cross-tabulation chi square analysis, is presented in Table 12. Differences were indicated according to practical in four of the six questions, none within the pre-laboratory section, and all questions were different based upon gender. In this analysis of difference there was some variation between the two statistical techniques.

| | ANOVA | | | Chi-square analysis | | |
|---|---|---|---|---|---|---|
| | Practical | Prelab | Gender | Practical | Prelab | Gender |
| The lab manual provided clear background theory to aid my understanding (q5) | 0.040 | 0.659 | 0.010 | 0.755 | 0.856 | 0.031 |
| I couldn't engage fully with the subject matter because there was too much to process (q16) | 0.002 | 0.864 | 0.002 | 0.123 | 0.907 | <0.001 |
| There were too many requirements I had to follow while doing this experiment (q13) | <0.001 | 0.065 | 0.012 | <0.001 | 0.583 | <0.001 |
| The experiment reinforced the background theory (q11) | 0.391 | 0.278 | <0.001 | 0.860 | 0.395 | <0.001 |
| I was so confused in the laboratory that I ended up following the manual without linking what I was doing with the underlining theory (q6) | 0.325 | 0.333 | 0.003 | 0.412 | 0.340 | <0.001 |
| I understood what I was doing in this experiment (q10) | 0.008 | 0.425 | 0.016 | 0.016 | 0.356 | 0.057 |

**Table 12. Analysis of difference in response for each questions in the theme theory based upon the categorical variables practicals, pre-laboratory work (prelab) and c) gender using on-way ANOVA (Minitab™) and Crosstabs and chi-square analysis (SPSS™).**

A comparison of responses based upon experiment is presented in Table 13 and the overall responses are provided for comparison. Statistically significant differences were reported for four of the six questions. It appears that there was some difference in response based upon the experiment in relation to perceived clarity of the instructions in the laboratory manual (q5 - *The lab manual provided clear background theory to aid my understanding*) with the means ranging between 5.20 for the organic practical, to 5.69 for the (easier) enthalpy practical. For Question 10 of the survey, *I understood what I was doing in this experiment*, it was found that the organic functional group experiment (*M = 5.44*, *SD = 1.28*) was lower than the other three experiments. The students were asked about the level of engagement (q16) and they reported that they slightly disagreed with the statement for all questions (Mean range 2.23 – 3.02). Similar to the laboratory guidance, their responses appear to correlate with the difficulty of the practical. A similar trend was observed in the number of requirements that needed to be completed. In all experiments, students agreed with the statement that the practical reinforced the underlying theoretical concepts (q11), and they disagreed with the statement that they participated in shallow learning by simply going through the motions (q6).

| Variable | Prac | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| The lab manual provided clear background theory to aid my understanding (q5) | Overall | 439 | 6 | 5.45 | 6.00 | 1.26 |
| | Cobalt | 106 | 3 | 5.40 | 6.00 | 1.31 |
| | Enthalpy | 127 | 1 | 5.69 | 6.00 | 1.14 |
| | Kinetics | 112 | 0 | 5.46 | 6.00 | 1.27 |
| | Organic Functional Group | 94 | 2 | 5.20 | 5.00 | 1.30 |
| I couldn't engage fully with the subject matter because there was too much to process (q16) | Overall | 428 | 17 | 2.56 | 2.00 | 1.48 |
| | Cobalt | 105 | 4 | 2.54 | 2.00 | 1.40 |
| | Enthalpy | 120 | 8 | 2.23 | 2.00 | 1.33 |
| | Kinetics | 111 | 1 | 2.56 | 2.00 | 1.52 |
| | Organic Functional Group | 92 | 4 | 3.02 | 3.00 | 1.60 |
| There were too many requirements I had to follow while doing this experiment (q13) | Overall | 425 | 20 | 2.79 | 2.00 | 1.51 |
| | Cobalt | 103 | 6 | 2.72 | 2.00 | 1.48 |
| | Enthalpy | 119 | 9 | 2.39 | 2.00 | 1.21 |
| | Kinetics | 111 | 1 | 2.60 | 2.00 | 1.43 |
| | Organic Functional Group | 92 | 4 | 3.63 | 4.00 | 1.67 |
| The experiment reinforced the background theory (q11) | Overall | 428 | 17 | 5.45 | 6.00 | 1.24 |
| | Cobalt | 105 | 4 | 5.34 | 6.00 | 1.41 |
| | Enthalpy | 120 | 8 | 5.61 | 6.000 | 1.06 |
| | Kinetics | 111 | 1 | 5.42 | 6.00 | 1.21 |
| | Organic Functional Group | 92 | 4 | 5.39 | 5.00 | 1.28 |
| I was so confused in the laboratory that I ended up following the manual without linking what I was doing with the underlining theory (q6) | Overall | 441 | 4 | 2.45 | 2.00 | 1.41 |
| | Cobalt | 107 | 2 | 2.36 | 2.00 | 1.38 |
| | Enthalpy | 128 | 0 | 2.39 | 2.00 | 1.28 |
| | Kinetics | 112 | 0 | 2.41 | 2.00 | 1.50 |
| | Organic Functional Group | 94 | 2 | 2.69 | 2.00 | 1.49 |
| I understood what I was doing in this experiment (q10) | Overall | 442 | 3 | 5.68 | 6.00 | 1.17 |
| | Cobalt | 108 | 1 | 5.55 | 6.00 | 1.20 |
| | Enthalpy | 128 | 0 | 5.94 | 6.00 | 1.01 |
| | Kinetics | 112 | 0 | 5.72 | 6.00 | 1.17 |
| | Organic Functional Group | 94 | 2 | 5.44 | 6.00 | 1.28 |

**Table 13. Descriptive statistics for theory themed questions according to experiment; significant differences marked red**

No statistically significant difference was observed based upon the compulsory requirement to complete a pre-laboratory work. Summary statistics are presented in Table 14.

| Variable | Prelab | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| The lab manual provided clear background theory to aid my understanding (q5) | No | 221 | 3 | 5.48 | 6 | 1.23 |
| | Yes | 218 | 3 | 5.43 | 6 | 1.29 |
| I couldn't engage fully with the subject matter because there was too much to process (q16) | No | 212 | 12 | 2.58 | 2 | 1.50 |
| | Yes | 216 | 5 | 2.55 | 2 | 1.46 |
| There were too many requirements I had to follow while doing this experiment (q13) | No | 211 | 13 | 2.93 | 2 | 1.55 |
| | Yes | 214 | 7 | 2.66 | 2 | 1.45 |
| The experiment reinforced the background theory (q11) | No | 212 | 12 | 5.51 | 6 | 1.16 |
| | Yes | 216 | 5 | 5.38 | 6 | 1.31 |
| I was so confused in the laboratory that I ended up following the manual without linking what I was doing with the underlining theory (q6) | No | 222 | 2 | 2.52 | 2 | 1.37 |
| | Yes | 219 | 2 | 2.39 | 2 | 1.44 |
| I understood what I was doing in this experiment (q10) | No | 222 | 2 | 5.72 | 6 | 1.16 |
| | Yes | 220 | 1 | 5.64 | 6 | 1.18 |

**Table 14. Descriptive statistics for pre-laboratory preparation themed questions according to pre-laboratory activity; significant differences marked red**

All questions in this theme indicated that gender impacts student response. The summary statistics are provided in Table 15. The females' responses to the questions indicated that they were more certain, with a more positive perception of laboratory learning and engagement.

| Variable | Gender | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| The lab manual provided clear background theory to aid my understanding (q5) | NA | 20 | 0 | 5.05 | 5 | 1.40 |
| | Female | 158 | 2 | 5.67 | 6 | 1.27 |
| | Male | 261 | 4 | 5.35 | 6 | 1.22 |
| I couldn't engage fully with the subject matter because there was too much to process (q16) | NA | 18 | 2 | 3.67 | 4 | 1.53 |
| | Female | 157 | 3 | 2.24 | 2 | 1.47 |
| | Male | 253 | 12 | 2.69 | 2 | 1.42 |
| There were too many requirements I had to follow while doing this experiment (q13) | NA | 18 | 2 | 3.94 | 4 | 1.39 |
| | Female | 156 | 4 | 2.60 | 2 | 1.59 |
| | Male | 251 | 14 | 2.83 | 2 | 1.42 |
| The experiment reinforced the background theory (q11) | NA | 18 | 2 | 4.89 | 5 | 1.18 |
| | Female | 157 | 3 | 5.75 | 6 | 1.18 |
| | Male | 253 | 12 | 5.30 | 5 | 1.24 |
| I was so confused in the laboratory that I ended up following the manual without linking what I was doing with the underlining theory (q6) | NA | 20 | 0 | 3.85 | 4 | 1.39 |
| | Female | 157 | 3 | 2.13 | 2 | 1.37 |
| | Male | 264 | 1 | 2.53 | 2 | 1.36 |
| I understood what I was doing in this experiment (q10) | NA | 20 | 0 | 5.20 | 5 | 1.24 |
| | Female | 158 | 2 | 5.88 | 6 | 1.10 |
| | Male | 264 | 1 | 5.60 | 6 | 1.19 |

**Table 15. Descriptive statistics for pre-laboratory preparation themed questions according to gender; significant differences marked red**

### 3.4.4 Laboratory tasks

**Three questions were included in the theme laboratory tasks. An analysis of difference using ANOVA and Cross-tabulation Chi square analysis is presented in**

Table 16. Significant differences were reported in: one question in the practical category; one of the pre-laboratory activities; and all the gender questions. Note that there is a slight difference in output based upon the statistical technique used.

| | ANOVA | | | Chi-square analysis | | |
|---|---|---|---|---|---|---|
| | **Practical** | **Prelab** | **Gender** | **Practical** | **Prelab** | **Gender** |
| I found the instructions in the lab manual clear (q15) | 0.160 | 0.954 | <0.001 | 0.255 | 0.210 | <0.001 |
| I recorded my data onto the proforma without thinking about how to analyse it (q1) | 0.227 | 0.553 | 0.202 | 0.290 | 0.215 | 0.020 |
| I had to clarify a lot of details with the demonstrator (q4) | <0.001 | 0.045 | 0.001 | <0.001 | 0.002 | 0.002 |

**Table 16. Analysis of difference in response for each questions based upon the catergorical variables practicals, pre-laboratory work (prelab) and c) gender using on-way ANOVA (Minitab™) and Crosstabs and chi-square analysis (SPSS™).**

When comparing the practicals, the students reported that there was no difference in the instructions within the laboratory manual. They slightly disagreed with the statement that they 'recorded data onto the proforma without thinking about how to analyse it' (q1), but there was no difference when comparing the practicals. There was a difference in Q4 - *I had to clarify a lot of details with the demonstrator* – and this again appears to be related to the difficulty of the experiment (i.e. the organic experiment appeared to be more challenging for the students).

| Variable | Prac | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| I found the instructions in the lab manual clear (q15) | Overall | 426 | 19 | 5.59 | 6.00 | 1.31 |
| | Cobalt | 105 | 4 | 5.66 | 6.00 | 1.32 |
| | Enthalpy | 119 | 9 | 5.77 | 6.00 | 1.19 |
| | Kinetics | 111 | 1 | 5.52 | 6.00 | 1.39 |
| | Organic Functional Group | 91 | 5 | 5.37 | 6.00 | 1.32 |
| I recorded my data onto the proforma without thinking about how to analyse it (q1) | Overall | 441 | 4 | 3.21 | 3.00 | 1.71 |
| | Cobalt | 107 | 2 | 3.08 | 3.00 | 1.72 |
| | Enthalpy | 128 | 0 | 3.07 | 3.00 | 1.65 |
| | Kinetics | 112 | 0 | 3.23 | 3.00 | 1.834 |
| | Organic Functional Group | 94 | 2 | 3.51 | 3.00 | 1.62 |
| I had to clarify a lot of details with the demonstrator (q4) | Overall | 435 | 19 | 3.27 | 3.00 | 1.59 |
| | Cobalt | 104 | 5 | 3.31 | 3.00 | 1.52 |
| | Enthalpy | 127 | 1 | 3.11 | 3.00 | 1.55 |
| | Kinetics | 111 | 1 | 2.94 | 2.00 | 1.68 |
| | Organic Functional Group | 93 | 3 | 3.85 | 4.00 | 1.48 |

**Table 17. Descriptive statistics for laboratory task themed questions according to experiment; significant differences marked red**

Question 4 of the survey, *I had to clarify a lot of details with the demonstrator*, reported that prelab preparation had a positive impact on students' understanding of experimental procedures (*M = 3.12*, *SD = 1.61*) compared to no prelab preparation (*M = 3.42*, *SD = 1.56*). Interestingly, the prelab component of the practicals produced a stronger effect in the female population (*M = 2.90*, *SD = 1.54*) than in the male population (*M = 3.40*, *SD = 1.57*).

| Variable | Prelab | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| I found the instructions in the lab manual clear (q15) | No | 210 | 14 | 5.60 | 6 | 1.26 |
| | Yes | 216 | 5 | 5.60 | 6 | 1.36 |
| I recorded my data onto the proforma without thinking about how to analyse it (q1) | No | 222 | 2 | 3.26 | 3 | 1.65 |
| | Yes | 219 | 2 | 3.16 | 3 | 1.78 |
| I had to clarify a lot of details with the demonstrator (q4) | No | 220 | 4 | 3.42 | 3 | 1.56 |
| | Yes | 215 | 6 | 3.17 | 3 | 1.61 |

**Table 18. Descriptive statistics for pre-laboratory preparation themed questions according to pre-laboratory activity; significant differences marked red**

The response based upon gender was again statistically significantly different. As in other themes females are appear to be more definitive in their responses.

| Variable | Gender | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| I found the instructions in the lab manual clear (q15) | NA | 18 | 2 | 4.72 | 5 | 1.36 |
| | Female | 156 | 4 | 6.00 | 6 | 1.14 |
| | Male | 252 | 13 | 5.40 | 6 | 1.34 |
| I recorded my data onto the proforma without thinking about how to analyse it (q1) | NA | 20 | 0 | 4.05 | 4.5 | 1.70 |
| | Female | 158 | 2 | 3.03 | 2 | 1.74 |
| | Male | 263 | 2 | 3.25 | 3 | 1.68 |
| I had to clarify a lot of details with the demonstrator (q4) | NA | 19 | 1 | 4.58 | 5 | 1.43 |
| | Female | 156 | 4 | 2.89 | 2 | 1.54 |
| | Male | 260 | 5 | 3.40 | 3 | 1.57 |

**Table 19. Descriptive statistics for pre-laboratory preparation themed questions according to gender; significant differences marked red**

### 3.4.5 Perception of experience

**Three questions were included in the theme perception of experience. An analysis of difference using ANOVA and Cross-tabulation/Chi square analysis is presented in**

Table 20. Significant differences were reported in: two questions of the practical category; one of the pre-laboratory activities; and all the gender questions. Note that there is a slight difference in output based upon the statistical technique used.

| | ANOVA | | | Chi-square analysis | | |
|---|---|---|---|---|---|---|
| | **Practical** | **Prelab** | **Gender** | **Practical** | **Prelab** | **Gender** |
| I didn't learn anything from doing this experiment (q3) | 0.785 | 0.780 | 0.001 | 0.345 | 0.195 | 0.011 |
| I felt overwhelmed while completing this experiment (q7) | 0.028 | 0.701 | 0.120 | 0.020 | 0.055 | <0.001 |
| I enjoyed completing this experiment (q2) | <0.001 | 0.010 | 0.001 | 0.002 | 0.015 | 0.260 |

**Table 20. Analysis of difference in response for each questions based upon the categorical variables practicals, pre-laboratory work (prelab) and c) gender using on-way ANOVA (Minitab™) and Crosstabs and chi-square analysis (SPSS™).**

A comparison of responses based upon experiment is presented in Table 21 and the overall responses are provided for comparison. Students disagreed with the statement that they 'did not learn anything from doing this experiment', and there was a statistically significant difference between the responses per practical. The students indicated that they disagreed with the statement 'I felt overwhelmed while completing this experiment' (q7), and the responses appear to change relative to the perceived difficulty of the practical. The students reported that they enjoyed completing all of the experiments, and in contrast to other responses, the enjoyment increased with the difficulty of the practical session.

| Variable | Prac | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| I didn't learn anything from doing this experiment (q3) | Overall | 434 | 11 | 2.34 | 2.00 | 1.20 |
| | Cobalt | 105 | 4 | 2.27 | 2.00 | 1.10 |
| | Enthalpy | 126 | 2 | 2.32 | 2.00 | 1.16 |
| | Kinetics | 112 | 0 | 2.44 | 2.00 | 1.33 |
| | Organic Functional Group | 91 | 5 | 2.33 | 2.00 | 1.21 |
| I felt overwhelmed while completing this experiment (q7) | Overall | 439 | 6 | 2.55 | 2.00 | 1.70 |
| | Cobalt | 107 | 2 | 2.45 | 2.00 | 1.58 |
| | Enthalpy | 127 | 1 | 2.24 | 2.00 | 1.58 |
| | Kinetics | 111 | 1 | 2.70 | 2.00 | 1.85 |
| | Organic Functional Group | 94 | 2 | 2.88 | 2.00 | 1.73 |
| I enjoyed completing this experiment (q2) | Overall | 440 | 5 | 5.40 | 6.00 | 1.31 |
| | Cobalt | 107 | 2 | 5.56 | 6.00 | 1.36 |
| | Enthalpy | 127 | 1 | 4.94 | 5.00 | 1.35 |
| | Kinetics | 112 | 0 | 5.56 | 6.00 | 1.23 |
| | Organic Functional Group | 94 | 2 | 5.65 | 6.00 | 1.11 |

**Table 21. Descriptive statistics for perception of experience themed questions according to experiment; significant differences marked red**

Students disagreed with the statement that they did not learn anything from doing the experiment, and there was a difference when comparing the addition of pre-laboratory activity. Similarly, pre-laboratory activity had no impact upon students feeling overwhelmed in the experiment. We would have anticipated that the compulsory pre-laboratory activity would have had an impact on students feeling, or not feeling, overwhelmed in the experiment. Interestingly, students reported slightly higher rates of 'enjoyment' (q2) for the experiments that included a pre-laboratory activity.

| Variable | Prelab | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| I didn't learn anything from doing this experiment (q3) | No | 217 | 7 | 2.32 | 2 | 1.18 |
| | Yes | 217 | 4 | 2.35 | 2 | 1.22 |
| I felt overwhelmed while completing this experiment (q7) | No | 221 | 3 | 2.52 | 2 | 1.67 |
| | Yes | 218 | 3 | 2.58 | 2 | 1.72 |
| I enjoyed completing this experiment (q2) | No | 221 | 3 | 5.24 | 5 | 1.30 |
| | Yes | 219 | 2 | 5.56 | 6 | 1.29 |

**Table 22. Descriptive statistics for perception of experience themed questions according to pre-laboratory activity; significant differences marked red**

Differences in response based upon gender were found in this theme. Similar to other questions female students appeared to respond more strongly in the positive or negative direction.

| Variable | Gender | N | N* | Mean | Median | StDev |
|---|---|---|---|---|---|---|
| I didn't learn anything from doing this experiment (q3) | NA | 18 | 2 | 2.44 | 2 | 1.25 |
| | Female | 155 | 5 | 2.08 | 2 | 1.22 |
| | Male | 261 | 4 | 2.49 | 2 | 1.16 |
| I felt overwhelmed while completing this experiment (q7) | NA | 20 | 0 | 3.65 | 4 | 1.39 |
| | Female | 156 | 4 | 2.33 | 2 | 1.67 |
| | Male | 263 | 2 | 2.59 | 2 | 1.70 |
| I enjoyed completing this experiment (q2) | NA | 20 | 0 | 5.15 | 5.5 | 1.39 |
| | Female | 157 | 3 | 5.69 | 6 | 1.15 |
| | Male | 263 | 2 | 5.24 | 5 | 1.36 |

**Table 23. Descriptive statistics for perception of experience themed questions according to gender; significant differences marked red**

## 3.5 Conclusions

In this study we investigated the effectiveness of the introduction of online testing prior to the laboratory learning activity. Specifically, this study aimed to test the theory that we are at times exceeding the capacity of the working memory and that this causes students to disengage. Based upon the working memory model we would recommend the redistribution of the components of the laboratory education experience into manageable activities so that the students can focus on the core of each learning exercise. Limited evidence was found to support the hypothesis that the addition of pre-laboratory activities increases positive student perception of the overall laboratory class.

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# 4 Dissemination strategies and outputs

A number of dissemination of strategies have been included in this project and some of these will be on-going in 2016. These include:

- Inclusion of stakeholders from the School of Science that teach in first year chemistry course in the project team.
- Widespread engagement with other academics regarding best practice and how this may impact further laboratory classes run at RMIT, specifically in the later years.
- Conduction of an informal session on the findings of our research to interested academics within the School of Science.
- Participation in local (state, national) education conferences and presentation of results in 2016 at appropriate forums.
- Participation at in-house education forums hosted by the Dean of Learning Deputy Dean Teaching & Learning in the School of Science.
- Generation of a manuscript to publish the findings in an appropriate peer-review education journal.

# 5 Evaluation of project outcomes

## 5.1 Planned process

This project proceeded as outlined in the project proposal. Specifically:

- A research assistant was recruited in January to work on the project one day per week for the entire year
- The project team met weekly to discuss the experimental design for the experimental/survey completed during semester 2, 2015.
- A student survey was completed as part of this research project in semester 2, 2015. Human ethics approval was obtained BSEHAPP 32-15 SPENCER-CLARKE Optimising Experimental Laboratory Classes to Maximise Student Learning Outcomes
- A total of 128 students from the course *CHEM1031 Chemistry of Materials 2* were surveyed to determine attitudes towards the additional pre-laboratory work.
- Eight laboratory demonstrators working for *CHEM1031 Chemistry of Materials 2 were* surveyed to determine their perception of student attitudes towards the additional pre-laboratory work.
- Members of the project team have participated in education forums in 2015.
- Key aspects of the project were assigned to various team members and communication throughout the project was completed through phone and email as needed.

## 5.2 Variation to processes

The project proceeded largely as anticipated. The key goal was to research the impact of reducing the impact of 'overloading' the student working memory in practical classes. Based upon a literature review it was decided to trial an increased pre-laboratory component. This fits in the 'flipped classroom' educational model where students are expected to heavily engage with subject material prior to attending structured learning activities, which in this case was a laboratory class.

## 5.3 Proposed project improvements

Due to limitations of budget and therefore time available for staff to conduct the formal research it was determined that we would look at surrogate measures of student performance (i.e. satisfaction). Ideally, to explore the hypothesis of the working memory, we would be required to run a much more controlled experiment.

## 5.4 Factors that helped and hindered in the achievement of the outcomes

The factors that have helped the achievement of the outcomes are:

- The commitment of the project team throughout 2015.
- A flexible and friendly project team.

Good relationships between staff and students, specifically positive relationship of the course coordinator Dr Spencer with the laboratory demonstrators and participating students.