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Teaching STEM for conceptual change:
Lessons from large classes in biomedical science

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Abstract

Despite the best efforts of academics, some students leave the undergraduate science courses with uncorrected misconceptions. There are several possible explanations for the persistence of misconceptions through and beyond undergraduate education, one of which is due to large class sizes. It seems, however, that large class teaching will be a continued response to the expansion of higher education. Therefore, it is imperative for academics to introduce teaching methods that are suited to large class settings and that will arrest problems that lead to uncorrected misconceptions. Conceptual change theory is one of the prevailing theoretical approaches to transforming misconceptions into conventional scientific understanding by reorganising or modifying the ideas underlying the misconception. One of the best approaches academics can take to fostering conceptual change is to infuse active learning into their teaching practice.

In this thesis, I propose an active learning intervention that potentially fosters conceptual change in a large class setting, as well as presenting the theoretical underpinnings of the development of this intervention. I started by enquiring into the current pedagogical practices of Australian biomedical science academics in order to understand how they cope with the mass education context, and whether there are specific obstacles to the introduction of active learning into their classrooms. Findings indicate that, despite identifying themselves as traditional teachers, the current pedagogical practices of Australian biomedical science academics exhibit potential in 'teaching for conceptual change' by being reflective teachers, by shifting to non-traditional teaching, and by collaborating with their colleagues to design the curriculum. Next, I probed the precursors for conceptual change learning experienced by interviewing students. By capitalising on the cognitive disequilibrium generated by misconceptions, I was able to further inform the development of the intervention. A contradictory understanding of current knowledge triggers cognitive disequilibrium because students are unable to bridge the gap between their prior knowledge and an incoming information. Findings show that the amount of prior knowledge, regardless of the quality, appeared to predict students' degree of confidence in it. In turn, the degree of confidence in prior knowledge appeared to predict a student's decision to change their mind in a collaborative setting; and the degree of confidence in prior knowledge also appeared to predict learning and retention of concepts. Finally, drawing from the notion that cognitive disequilibrium, if properly induced, can lead to conceptual change, I propose a misconception-driven intervention that potentially induces cognitive disequilibrium by using intentionally flawed scientific

manuscripts. This active learning intervention showed comparable improvements with a didactic approach in terms of students' conceptual understanding and student self-reported engagement, however, independent classroom observers observed that this intervention improved student engagement. A review of the extant literature on student engagement suggests that engagement is predominantly linked to improved learning outcomes.

I would argue further that for the learning process to ultimately lead to conceptual change, the responsibility does not only depend on the improved pedagogical practices of academics, but also more importantly, on the students themselves. Our role as academics is to integrate active learning methods that promote self-regulation, which will enable students to reflect on their own understanding and become more metaconceptually aware for them to recognise a potential state of cognitive disequilibrium. To be able to do this, academics should attend education conferences or fora and professional development opportunities to help them improve their pedagogical practice.

Declaration

This is to certify that:

i. The thesis comprises only my original work towards the PhD.

ii. Due acknowledgment has been made in the text to all other material used.

iii. The thesis is fewer than 100,000 words in length, exclusive of tables, bibliographies, and appendices.

(Sgd) Allen A Espinosa

July 2019

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AAE

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Chapter 1

Introduction

The universal access to facts and declarative knowledge through the Internet paved the way to a well informed and well-educated society. This ease of access to information, however, has also brought challenges to schools and universities - while the Internet offers facts, it is also littered with fictitious information. This fictitious information is particularly a problem to the scientific community. Twenty-first century learners have often been vulnerable to this fabricated and distorted information because of their technology-dependent nature. If left unchecked, it may eventually bring about misconceptions. Thus, a call to develop critical thinking in the curriculum had been the battle cry of present-day schools and universities to help students discern and sort out factual information from those that are not and avoid acquiring or reinforcing misconceptions.

What is misconception?

Misconception is not explicitly defined in the science education literature (Maskiewicz & Lineback, 2013). Most authors, however, describe misconceptions as ideas that deviate from scientifically accepted ones (e.g. Heddy & Sinatra, 2013; Hickey & Zuiker, 2012; Opfer, Nehm, & Ha, 2012). This definition is also similar to the description given by the National Research Council (2012a): "understandings or explanations that differ from what is known to be scientifically correct" (p. 58). I used the same definition to refer to misconceptions in this study.

There is an ongoing debate on the use of the term 'misconception' in the science education literature. Some researchers argue that 'misconception' is no longer relevant as the term is linked to learning theories that are already outdated and no longer effective in modern day classrooms (Maskiewicz & Lineback, 2013). Hence, the proposed alternative terms: alternative conceptions or frameworks (Abraham, Perez, Downey, & Herron, 2012; Wandersee, Mintzes, & Novak, 1994), common sense conceptions (Chi, 2005), and naïve conceptions (Fisher & Moody, 2002). On the contrary, other researchers recommend the continuous use of the term in the science education literature because there is no existing body of research suggesting that the term is outdated and has been rejected and replaced with alternative terms (Leonard, Kalinowski, Andrews, & Wenderoth, 2014). Leonard et al. (2014) believe that term misconception will continuously be relevant in the education literature "yesterday, today, and tomorrow" (p. 179). While both sides presented sound arguments, I also

agree with the latter - the continued use of the term misconception in the education literature, so as not to muddy the waters. I used the term misconception here and in my previous work (Espinosa, Marasigan, & Datukan, 2016).

Anchoring conception, misconception, and preconception: a clarification

Students enter schools or universities with existing ideas about the world. These ideas that the students have prior to entering into a learning institution for a specific field are referred to as preconceptions (Clement, Brown, & Zietsman, 1989). Clement (1993) suggests that the term 'preconception' can be used as an alternative for 'misconception.' However, the description of preconception is inconsistent with that of misconception. Preconceptions can either be accurate or inaccurate. Thus, "not all preconceptions are misconceptions" (Clement, 1993, p. 1241; Clement et al., 1989). Preconceptions that disagree with accepted concepts as a result of 'systematic patterns of errors' are called misconceptions (Bensley & Lilienfeld, 2015; Vosniadou, 2009). Preconceptions that conform with scientifically accepted theories, on the other hand, are called anchoring conceptions (Clement, 1993). In this study, I used the term 'prior knowledge' to refer to preconceptions.

Where do student misconceptions in science come from?

Misconceptions emerge in two different ways - factual and ontological. Factual misconceptions are derived from distorted information presented in the media, educational institutions, learning materials, and communication with other people (Hughes, Lyddy, & Kaplan, 2013). Ontological misconceptions (also referred to as 'naïve' or 'folk' science) came from intuitive or common sense theory-like beliefs rooted from an individual's personal understanding of things (Hughes et al., 2013), which were formed because people naturally look for explanations of things around them, resulting to misconceptions. Hughes et al. (2013) argued that people hold instinctive, practical beliefs strongly because they are easier to understand compared to the complex ideas formally taught in science, for example the misconception that the earth is flat.

Another scenario that brings about misconceptions is when students try to integrate the factual information with their dissenting misconceptions, resulting in a 'synthetic model' (Vosniadou, 2009). This model put together accurate and inaccurate ideas. An example of a 'synthetic model' is the misconception amongst many children about how plants grow. They believe that plants only grow through the nutrients from the soil. When photosynthesis, which is a process that helps plants grow, was taught to these children, they combine their

misconception with this new knowledge. They conclude that photosynthesis simply helps the plants breathe and that the cause of plants' growth are still the nutrients and minerals from the soil. In this study, I focused on misconceptions in biochemistry and molecular biology (Table 1.1) as a representative example of the wider issue in the STEM disciplines.

Table 1.1

Common incorrect ideas in biochemistry and molecular biology

Concept	Incorrect idea or confusion
*Biochemistry**	
Bond energy	Bond formation requires energy.
Alpha helix	The interior of an alpha helix contains the side chains of the amino acid residues.
London dispersion	A dipole is not involved in the interaction between non- polar molecules.
Hydrogen bonding	All hydrogens are capable of hydrogen bonding.
Free energy	The free energy change for a process indicates whether or not the process releases heat.
*Molecular Biology***	
Evolutionary theory	Mutations are directed, not random.
Genetic material	Bacteria can have RNA as genetic material, but viruses have DNA only.
Structures of macromolecular building blocks	The differences between the molecular structures of phospholipids and fatty acids and between monosaccharides, amino acids, and nucleotides.
The properties of macromolecules	The properties of polar molecules.
Biochemical reaction dynamics	Enzymes act by changing the equilibria of chemical reactions.
Movement of molecules through membranes	Ions, because of their small size, can diffuse through membranes.
Flow of energy and matter	Oxygen is used in the formation of CO_2 during cellular respiration.
Inheritance of chromosomes	Individual chromosomes can contain genetic material from both parents.
Regulation of gene expression	Promoter regions are part of the coding region of a gene.

*Adapted from Villafañe, Loertscher, Minderhout, and Lewis (2011, p. 215)
**Based on Shi, Wood, Martin et al. (2010)

Why is misconception a problem?

The problem with misconceptions is that they impede the students' learning process because of two things: (1) students firmly believe them and they are hard to be rectified by

typical teaching methods (Hughes et al., 2013), and (2) they affect students' acquisition of new ideas because they made it difficult for the students to fully grasp information that are different from their already held misconceptions (Kuhle, Barber, & Bristol, 2009). Hence misconceptions impairs the learning process (Chinn & Malhotra, 2002; Hughes et al., 2013). Students are also unable to apply what they have learned from one misconception to other misconceptions, which are derived from the same suppositions (Kowalski & Taylor, 2009).

Misconceptions and large class teaching

Research shows that many biology students finish their undergraduate courses with a considerable number of misconceptions (Nehm & Reilly, 2007), which they then try to apply to a more advanced context (Tanner & Allen, 2005). As to why these misconceptions exist and are not addressed is due to different factors. One of them is large class sizes with traditional teaching styles. A risk of large class teaching is that students go through the class with uncorrected misconceptions (Finn & Achilles, 1999). It is easier for the lecturer to employ a traditional lecture instead of a more active method of teaching in this type of classroom setting. The traditional lecture format, however, fails to expose students to meaningful learning experiences (Knight & Wood, 2005; Smith, Stewart, Shields et al., 2005) that will help them develop critical thinking skills (National Research Council, 2007; Wright & Boggs, 2002). Critical thinking skills are necessary for students to recognise a potential misconception by intellectually processing information collected through observation or experience and by carefully analysing, applying, and evaluating the information (Scriven & Paul, 1987). The one-way approach of learning provided by direct instruction or traditional lecture also hinders the process of conceptual change (Leonard et al., 2014).

Helping students overcome misconceptions through conceptual change teaching

Conceptual change, as Clement (1993) puts it, means displacing, modifying, improving, replacing or suppressing a misconception. In order for conceptual change to occur, an appropriate pedagogy (for example, active learning) that can initiate motivation in students should be implemented to help them reorganise their scientifically inaccurate ideas to scientifically accepted ones (Chi & Roscoe, 2002).

In line with the current research in education (e.g. Ferreira, Lemmer, & Gunstone, 2019; Tanner & Allen, 2005), this thesis argues that the best instruments to address a misconception are the wrong answer committed to by the students. These answers can be used in developing effective and efficient learning experiences that will foster conceptual change. In addition, the

National Research Council (2012b) suggested that misconceptions should be addressed by the following process: identification of commonly recurring misconceptions, determination of the origin and structure of a misconception, considering the cognitive and affective aspects required for conceptual change creation and evaluation of strategies to aid conceptual change, and determination of the support and resources needed by instructors to effectively implement the conceptual change strategies.

Intervention studies in conceptual change teaching

The development of conceptual change approaches in teaching science started in the 1980s (Duit & Treagust, 2003). Most of these teaching strategies were influenced by the classical approach of Posner, Strike, Hewson, and Gertzog (1982) to conceptual change, in which the teacher designs an intervention based on the identified misconceptions of students (Duit & Treagust, 2003). Intervention studies involving conceptual change approaches in teaching science showed considerable efficacy compared with more traditional teaching methods (Duit & Treagust, 2003; Duit, Treagust, & Widodo, 2013).

Even though most research on conceptual change approaches has reported success compared with traditional approaches (Duit et al., 2013; Guzzetti, Snyder, Glass, & Gamas, 1993; Wandersee et al., 1994), the outcomes of conceptual change approaches and other teaching approaches are difficult to compare because each method addresses different learning goals (Duit et al., 2013). When conceptual change is combined with other teaching approaches, success can be attributed not only to conceptual change, but to other teaching methods as well (Duit et al., 2013), which is also the case in this study that combined misconception-based reading within a social active tutorial.

Duit and Treagust (2003) identified three major shortcomings in intervention studies involving conceptual change. First, rather than focussing on the cognitive processes that led to the development of misconceptions, studies on conceptual change approaches target the individual's misconceived scientific knowledge. Hence, only a few misconceptions in science has been resolved in a single class. However, if the intervention study focusses on developing self-regulated learners, the student would be able to detect a potential misconception and refute it eventually. Self-regulated learners are independent learners who "transform their mental abilities into academic skills" (Zimmerman, 2002, p. 65).

The second limitation identified by Duit and Treagust (2003) is that the studies put too much emphasis on a rational approach to teaching science by following the sequence in teaching scientific concepts based on prerequisite knowledge. This approach, however,

neglects affective and other domains in learning (Duit & Treagust, 2003; Pintrich, Marx, & Boyle, 1993). Hence, intervention studies involving conceptual change have started to consider affective and emotional aspects because these aspects also change when conceptual change happens (Tyson, Venville, Harrison, & Treagust, 1997; Zembylas, 2005). This limitation was further addressed by Sinatra and Pintrich (2003) on their work on intentional conceptual change, in which they described intentional conceptual change as "the goal-directed and conscious initiation and regulation of cognitive, metacognitive, and motivational processes to bring about a change in knowledge" (p.5).

Although present research on conceptual change approaches show considerable inclusion of affective and emotional domains, there are still challenges in fully realising a more inclusive conceptual change approach (Duit & Treagust, 2012). A call for the inclusion of student engagement and interest in conceptual change approaches has also been apparent in the recent years (Duit & Treagust, 2012). Despite this, however, most studies in conceptual change teaching still focus on measuring cognitive outcomes and ignored affective outcomes because affective aspects in learning are not considered as an 'outcome' by themselves (Duit & Treagust, 2012).

The third limitation identified by Duit and Treagust (2003) is that most conceptual change approaches focus on monistic approach to teaching, which do not consider the different epistemological orientation of individual students (Duit & Treagust, 2003). Epistemological orientation refers to the different epistemological beliefs of students or the "theories and beliefs [students] hold about knowing" (Hofer & Pintrich, 1997, p. 88). Thus, Duit and Treagust (1998) hypothesised that for a conceptual change teaching approach to realise productive learning outcomes, it must consider both social and personal aspects.

This thesis

In this thesis, I have propose an active learning intervention suitable for large class setting and which capitalises on the misconceptions of students as a core teaching strategy. I divided my PhD project into three phases, which is also the basis for the arrangement of the chapters in this thesis. I start by reviewing the extant literature on large class teaching as well as active learning methods that are potentially applicable in the mass education context. Next, I look into the contemporary pedagogical and curriculum design practices of Australian biochemistry and molecular biology academics in order to understand how they cope with the large class context. Then, I probe into the precursors for conceptual change learning by exploring the impact of combining two different characteristics of a learner to the degree of

conceptual change: prior knowledge (a cognitive factor) and confidence in prior knowledge (an affective factor). Finally, I develop, describe, and evaluate an intervention by capitalising on the cognitive disequilibrium generated by misconceptions using intentionally flawed scientific manuscripts. Cognitive equilibrium emerged when there are "contradictions, obstacles, and anomalies" in the information being presented (Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005, p. 1235).

Research Questions

The need for active learning and student-centred teaching that will initiate conceptual change in a large class setting prompted this study. This project investigates active learning methods that capitalise on targeting misconceptions as a core teaching strategy in enhancing conceptual understanding and student engagement. Three major research questions were investigated in this project:

1. What are the current pedagogical and curriculum design practices of Australian biochemistry and molecular biology academics? Are there specific blocks to the introduction of active learning into a large classroom setting? Interviews, free-response survey, document analysis and classroom observations were carried out to answer these research questions.
2. What role does prior knowledge and confidence in prior knowledge play in conceptual change? Interviews with students have been conducted, after exposing them to a misconception-driven tutorial, to answer this research question.
3. Do students in a newly designed active learning tutorial have higher improvement in conceptual understanding, and are they more engaged, compared to students in a more traditional tutorial? A conceptual pre- and post-test and engagement self-report have been administered, after exposing the students to an active learning and didactic tutorial, to answer this research question. Observations by two independent observers were employed to triangulate the self-reported student engagement.

Structure of the thesis

This thesis is divided into the three different phases, in the development of the active learning intervention described in Chapter 5.

Chapter 2 explores the literature to investigate the problems inherent in large class teaching and the rationale for incorporating active learning into large class settings. In this chapter, I present a collection of active learning approaches that can possibly be utilised in

large STEM classes as well as some of the common barriers to the integration of active learning and how to overcome them. This chapter is at the second stage of review in the *International Journal of Science and Mathematics Education*.

Chapter 3 explores the current pedagogical and curriculum design practices of Australian biochemistry and molecular biology academics in order to understand how they cope with the mass education context, and whether there are specific blocks to the introduction of active learning into their classrooms. This part of the project has been approved by the Human Research Ethics Committee of the University of Melbourne, with Project Numbers 1545425.1 (for the interview and survey) and 1545924.1 (for the classroom observation and document collection). The results from this chapter have been presented at the *Australian Conference on Science and Mathematics Education 2016* and assembled into two manuscripts, one of which is published in the *Australian Educational Researcher* (DOI: 10.1007/s13384-019-00369-5).

Chapter 4 explores the use of misconceptions in biochemistry and molecular biology as opportunities to create cognitive disequilibrium among the students to enhance their conceptual understanding. In this chapter, I present the potential precursors for conceptual change by exploring the relationship between cognitive (prior knowledge) and affective factor (confidence in prior knowledge) in the process of conceptual change. I also unpack the specific skills and qualities required to ultimately achieve conceptual change. This part of the project has been approved by the Human Research Ethics Committee of the University of Melbourne with Project Number 1543979.3. The results from this chapter have been presented at the *National Association for Research in Science Teaching (NARST) International Conference 2018* and have been accepted for oral presentation at the *European Science Education Research Association (ESERA) Conference 2019*. This chapter has been prepared as a paper for the *Journal of the Learning Sciences*.

Chapter 5 explores the effectiveness of a newly developed active learning intervention, compared to a didactic tutorial, in enhancing students' engagement and conceptual understanding in biochemistry and molecular biology. In this chapter, I examined if students are more engaged and have higher improvement in conceptual understanding through active learning or didactic tutorials. This part of the project has been approved by the Human Ethics Research Committee of the University of Melbourne with Project Number 1748697.1. The results from this chapter have been presented at the *Australian Conference on Science and Mathematics Education 2017* and at the *Annual Convention of the Philippine Society for*

Biochemistry and Molecular Biology in 2017. This chapter has been prepared as a paper for *Frontiers in Education*.

Chapter 6 presents a general discussion of the challenges in 'teaching STEM for conceptual change' in a large class setting as well as possible solutions to these challenges. In this chapter, I problematise 'disciplinary differences' and the 'teaching-research nexus,' questioning their relevance to modern day science education. I also present alternative interpretations to disciplinary differences and teaching-research nexus that is responsive to the needs of 21st century learners. Moreover, in this chapter, I present the conclusions drawn from this study by presenting its implications for research and professional practice in large class teaching in biochemistry and molecular biology, and also more broadly in other STEM disciplines.

Chapter 2

Active learning in STEM: Problems and solutions for large class teaching

Active learning has been found to be one of the most important means of ensuring that activities lead to long term learning. Despite this benefit, it is difficult to implement active learning strategies in some settings, particularly in large classes. In this chapter, I discuss the problems inherent in large class teaching and the rationale for incorporating active learning into large class settings. I present a collection of active learning approaches that have been implemented in large biomedical science classes, but also more broadly in STEM disciplines at different universities around the world: Socratic teaching, collaborative and cooperative learning, inquiry teaching, metacognitive teaching, contextualised and blended learning, and flipped classroom. I provide options suitable for academics interested in applying active learning to their large classes. I also discuss some of the common barriers to the integration of active learning and how to overcome them, such as the quality of teacher training and the difficulty of scaffolding active learning activities throughout the curriculum.

Keywords: active learning, large classes, biomedical sciences, Biochemistry, Molecular Biology, STEM

Introduction

Large class teaching is widespread across universities worldwide, despite many studies indicating that there are more negative than positive effects (e.g. Knight & Wood, 2005; Walker, Cotner, Baepler, & Decker, 2008). In fact, in most cases class sizes are still increasing as university education transitions from elite to mass to universal in many parts of the world. To address the problems brought about by large class sizes, academics are trying to find ways to innovate, and are exploring novel ways to integrate active learning into their large classes. Although there are many papers on issues related to large class sizes (e.g. Blatchford, Russell, Bassett, Brown, & Martin, 2007; Cuseo, 2007; Finn & Achilles, 1999; Stanley & Porter, 2002) and active learning (e.g. Eison, 2010; Faust & Paulson, 1998; Freeman, Eddy, McDonough et al., 2014; Michael, 2006; Prince, 2004), only a few discuss the application of active learning specifically to solve the problems of large class settings in Science, Technology, Engineering and Mathematics (STEM) disciplines (Allen & Tanner, 2005; Herbert, Chalmers, Hannam, Terry, & Lipp, 2001; Smith et al., 2005; Walker et al., 2008). In this chapter, I suggest different ways to implement active learning in large STEM classes in a way that improves academic

achievement and the engagement of students. The specific context that I have used to inform STEM practices broadly are teaching practices in biomedical science classes. I present, here, the benefits of active learning to students, as well as some approaches to implementing active learning in large classes. I also discuss some of the limitations and precautions in the implementation of active learning.

Why are large class sizes the norm and why is this a problem?

Since the establishment of Higher Education Institutions (HEIs) some 900 years ago, one of the most common forms of instruction by academics, regardless of geographic region, is direct instruction (e.g. traditional lecture) (Brockliss, 1996; Huba & Freed, 2000). This is due to its efficiency in the rapid dissemination of comprehensive curricula using limited resources, and traditionally this has suited the areas of STEM because of the content-dense nature of the discipline (Donovan & Loch, 2013; Eison, 2010; Wright & Boggs, 2002). Direct instruction satisfies many teaching objectives in both kindergarten to 12th grade (K-12) education and HEIs, especially that of covering the amount of required content (Bransford, Brown, & Cocking, 2000; Hake, 1998; Walker & Jorn, 2007). However, the gains that can be obtained from direct instruction diminish when students are situated in a large class (Walker et al., 2008). This will be explored further in the next section about problems with large class cohorts.

Large class teaching has been a feature of most modern higher education institutions because of issues of funding (Cullen, 2011). Indeed, over the last thirty years, Australian universities have seen average class sizes, especially introductory classes in the sciences (e.g. Biology), grow from 100 (Rivers, 1986) to around 400 students (Allan, 2014; Herbert et al., 2001). This is also true of classes in biomedical science disciplines such as biochemistry and molecular biology (e.g. Davis, Hodgson, & Macaulay, 2012; Fildes, Kuit, O'Brien, Keevers, & Bedford, 2015; Rowland, Lawrie, Behrendorff, & Gillam, 2012; Rowland, Smith, Gillam, & Wright, 2011). Most of these STEM classes are conducted in the traditional lecture format (Herbert et al., 2001) with little evidence of active learning, due to factors such as broad course content, poor time availability, lack of materials, resistance of students to non-lecture approaches and resistance of lecturers (Eison, 2010). Furthermore, lecturers are typically hired because of their expertise in their discipline not because they have any knowledge or skill in pedagogy.

A review of the literature suggests that teachers of large classes who rely heavily on traditional lectures are often ineffective, due to a failure to motivate the students to engage in the meaningful intellectual experiences (Knight & Wood, 2005; Smith et al., 2005). Such

experiences are said to be the foundation of accurate knowledge and the skills necessary to achieve professional success, such as problem solving and critical thinking skills (National Research Council, 2007; Wright & Boggs, 2002). Traditional lectures can fail to motivate and stimulate the enthusiasm of the students, and often result in passive learning behaviour wherein students acquire superficial understanding (Beasley, 1995; Johnstone & Su, 1994; Weimer, 2002). This could then hinder students' future professional success because they are not equipped with the necessary knowledge and skills (Bransford et al., 2000; National Research Council, 2007; Wright & Boggs, 2002).

In biochemistry and molecular biology, and the biomedical sciences generally, the heavy reliance of academics on the traditional lecture format and large class sizes could lead to impediments to effective student learning such as: (1) the topics to be covered are compressed into a limited time; (2) limited capacity to respond to student diversity; (3) students lack motivation to attend lectures; and (4) difficulty giving feedback to students (Davis et al., 2012; Fildes et al., 2015; Rowland et al., 2011). The passivity of learners due to large lecture sizes is also exemplified by: low attendance, low motivation and emotional investment in the process of learning, lack of student preparedness and impoverished learning outcomes (Bligh, 2000; Cuseo, 2007; Milton, Pollio, & Eison, 1986; Penner, 1984; Slavin, 1991). It seems that these problems encountered in higher education institutions are not limited to Biomedical Science classes, as other fields of the sciences also suffer from the same predicaments (Ruiz-Primo, Briggs, Iverson, Talbot, & Shepard, 2011).

Student success in STEM courses is also put at risk by too much dependence on traditional lecture-style teaching. In a broad study, Freeman et al. (2014), found that, when compared to students taught with an active learning approach, "students taught with traditional lectures were 1.5 times more likely to fail" STEM courses in HEIs (Laneuville & Sikora, 2015, p. 141). To address this, various HEIs have implemented educational reforms (National Research Council-Committee on Undergraduate Science Education, 1997, 2003; National Science Foundation, 1996; Next Generation Science Standards, 2013) including the implementation of approaches aimed at enhancing metacognitive skills and skills that are essential for future professional success (American Association for the Advancement of Science, 1989, 2009; Boyer Commission on Educating Undergraduates in the Research University for the Carnegie Foundation for the Advancement of Teaching, 1998; Handelsman, Ebert-May, Beichner et al., 2004; National Research Council-Committee on Undergraduate Science Education, 2003; Project Kaleidoscope, 2006).

Why active learning?

Based on the principle that teaching should be student centered to develop critical thinking and independence (Bransford et al., 2000; Freeman, O'Connor, Parks et al., 2007), active learning approaches have become widespread practice in K-12 basic education schools in Australia, but not in HEIs (Aspland, n.d.; EYLF Professional Learning Program, 2010), partly due to large class sizes. It has been a challenge for education researchers even just to define active learning; there is a range of definitions adopted by researchers and practitioners (Hake, 1998). Operationally, active learning has been defined as acquiring and searching for new information, such that students are able to organise the information and communicate it to both their classmates and to other people (Allen & Tanner, 2005). It has also been defined as the moment when the instructor shifts from a heavy reliance on direct instruction to activities that enable learners to appreciate and understand a particular concept independently (Bransford et al., 2000). Active learning has five common elements: (1) students are involved in the process of learning, instead of simply listening to the teacher, (2) the emphasis of teaching is not on the transfer of knowledge, but on the development of skills, (3) students are exposed to activities promoting higher order thinking, (4) students are involved in a variety of activities, such as discussing, reading and writing, and (5) activities are geared towards exploring values and attitudes of students (Bonwell & Eison, 1991).

Active learning, intertwined with other student-centred approaches, ensures better understanding and retention of concepts being delivered in a class (Asokanthan, 1997; Deslauriers, Schelew, & Wieman, 2011; Meyers & Jones, 1993; Wieman, Deslauriers, & Gilley, 2013) particularly in science courses that require critical and problem solving skills (Armstrong, Chang, Brickman, & Ebert-May, 2007; DeHaan, 2005; Hake, 1998; Handelsman et al., 2004; Herreid, 1998; Smith et al., 2005; Zoller, 2000). Moreover, active learning can revolutionise a traditional lecture by motivating students to comprehend concepts effectively, addressing the varied learning profiles of students, reducing routine activities that favor dependence, and providing opportunities to be accountable for their own learning (Asokanthan, 1997; Kramarski & Mevarech, 2003; Mejia & Monterola, 2015). This was further reinforced by the National Research Council (2007), which encourages the shifting of traditional pedagogies in HEIs to a more result-oriented approach that supports students to be accountable for their own learning beyond the class experience where the concepts were learned. In addition, active learning has been extensively shown to help students situated at the lower end of the performance curve (Walker et al., 2008). The application of active learning in HEI classrooms has been examined in a diverse field of sciences (Ruiz-Primo et al., 2011), including

biology (Freeman et al., 2007; Haack, 2008; Jensen & Finley, 1996; Knight & Wood, 2005; Nehm & Reilly, 2007; Udovic, Morris, Dickman, Postlethwait, & Wetherwax, 2002) and chemistry (Niaz, Aguilera, Maza, & Liendo, 2002; Wright, 1996). However, the challenge is often to apply active learning techniques in situations of large class sizes and over-crowded curricula.

How can active learning be achieved in large class sizes?

Here I will present a critical synthesis of six different thematic approaches to integrating active learning into large class teaching: (1) Socratic teaching, (2) collaborative and cooperative learning, (3) inquiry teaching, (4) metacognitive teaching, (5) contextualised and blended learning, and (6) flipped classroom. If properly implemented, these active learning approaches would potentially promote better learning outcomes for the students.

Socratic teaching

The first of the active learning approaches is said to be the oldest but is still a powerful tool to foster critical thinking among students. Socratic teaching focuses on providing thought-provoking questions to students instead of feeding them with concepts. In this method, students deduce concepts by answering the questions posed by the lecturer or by their peers (Paul & Elder, 1997). The Socratic method "promotes critical thinking, active verbal participation, and individual self-motivation" (Hardman, 2016, p. 64). Table 2.1 presents some useful Socratic teaching methods.

Table 2.1.

Useful Socratic teaching methods for science academics

Approach	Brief Description	Further Resources
"Bookending" or purposeful questioning	The lecturer poses interesting questions either during the class or as an assignment for students to "offer the explanations, organize and summarise the course material, and find ways to fit new information into their existing conceptual frameworks" (Allen & Tanner, 2005, p. 263). Ideal for: Eliciting student participation within a lecture-based class. Advantages: The students deduce key concepts from the lecturer's questions. They also get immediate feedback from the lecturer regarding their answers. Challenges: Generating interesting and provocative questions to maintain interest but also focussing the discussion on key concepts.	Faust and Paulson (1998); Allen and Tanner (2005); Eison (2010)
On-the-spot or immediate feedback techniques (e.g. clickers, finger signals, flash cards)	The lecturer presents multiple choice questions and students answer on a class response system. The lecturer can use the responses as a springboard for discussion. This strategy enhances academic achievement (Johnson, 2014) and reduces test anxiety of students (Gilbert, Whitelock, & Gale, 2011; Way, 2012) Ideal for: Getting instant feedback from the lecturer, which may reduce misconceptions. Advantages: It is now easy to collect student responses using smart phones, without using dedicated clickers. Peer discussion can be employed if some students do not have internet access. Challenges: Generating higher order multiple choice questions.	Faust and Paulson (1998); Allen and Tanner (2005); Eison (2010); Ambruster, Patel, Johnson, and Weiss (2009); Waldrop (2015)
ConcepTest	An assessment with multiple-choice questions voicing common misconceptions is administered. Students respond by raising their hands with the number of fingers demonstrating their answer, or using a response tool (see above). Students discuss their answers with peers and once more submit an answer. Finally, the instructor gives the answer and explains the appropriate reasoning behind it. This method increases student engagement as well as attendance (Hall, Collier, Thomas, & Hilgers, 2005; Judson, Sawada, & Daiyo, 2002; Mazur, 1997) Ideal for: Confronting common misconceptions Advantages: Develops deep conceptual understanding rather than rote memorisation. Disadvantages: Takes time for the students to give a revised answer.	Mazur (1997); Chew (2004); Eison (2010)

Collaborative and cooperative learning

The second method for achieving active learning and student-centred instruction is through collaborative and cooperative learning. Although these two approaches rooted from different educational philosophies (Bruffee, 1995), their core element is the same - students interact in a group instead of working in solitary (Prince, 2004). Collaborative and cooperative learning can be employed in conjunction with other strategies (e.g. think-pair-share, concept mapping, role-playing and debates). It is based on the premise that students working collaboratively and cooperatively are learning more effectively than in an environment in which they are competing with one another. Learning groups can be classified into three categories: informal, formal or base groups (Johnson, Johnson, & Smith, 1991). Informal is when students are put together on the spot for a short task. Formal is when students are put together to work on a complex problem that will require longer amounts of time to complete. Base groups are composed at the start of the term and stay intact throughout the term. This approach is ideal for promoting teamwork and interpersonal skills among students. One of the many advantages of this method is that it develops critical thinking among students when they reflect and evaluate the ideas given by each member during the brainstorming process. However, if not addressed in class, students may also develop misconceptions from the brainstorming process. The approach is further explained in Faust and Paulson (1998), Prince (2004), Michael (2006), Armstrong et al. (2007), Ambruster et al. (2009), and Eison (2010).

Inquiry teaching

The third of the active learning approaches has been investigated thoroughly in chemistry (and later on in other STEM disciplines). The aim of inquiry teaching is that, while learning the core scientific concepts, students are also developing desirable skills such as "oral and written communication, problem solving, critical thinking and teamwork" (Loertscher, 2009, p. 1). For example, Process Oriented Guided Inquiry Learning (POGIL), through the use of a learning cycle paradigm, supports students in improving their grasp and understanding of new ideas and information (National Research Council Committee on the Foundations of Assessment, 2001). This learning cycle paradigm starts with *Exploration*, followed by *Concept invention*, and finally *Application*. Within these stages, students can challenge each other's answers to a particular question, giving other students and the teacher the opportunity to assess and deliberate on ideas and concepts (Bailey, Minderhout, & Loertscher, 2012). The classroom setting bears a resemblance to Socratic questioning (Loertscher, 2009), as the questions direct

students to think logically and analyse concepts (Minderhout & Loertscher, 2008). Table 2.2 presents other useful inquiry teaching methods.

Table 2.2.

Useful inquiry approaches for science academics

Approach	Brief Description	Further Resources
Learning cycle (e.g. 5E - engage, explore, explain, elaborate and evaluate)	Engage: interesting short activities allow students to organise their prior knowledge and prepare to acquire new knowledge. Explore: students explore the central concepts or ideas in specific tasks. Explain: students validate their understanding by communicating with others. Elaborate: they put the new and old information together to give much clearer meaning to the concept. Evaluate: the understanding of concepts is evaluated. Ideal for: Enabling students to deduce concepts from a systematic learning cycle instructional model (Bybee, Taylor, Gardner et al., 2006; Stamp & O'Brien, 2005). Advantages: How an individual acquires new knowledge and connects it to their prior knowledge is considered. Challenges: Considerable effort and time is required constructing classroom activities that will connect students' prior knowledge and new ideas.	Allen and Tanner (2005); Liu, Peng, Wu, and Lin (2009)
Workshops (e.g. "Workshop Biology")	Based on the principle of "science as inquiry". Both the lecture and laboratory classes are investigative in nature - students work in small groups and deduce key concepts from meaningful activities or tasks. This method enhances "conceptual learning and understanding of scientific reasoning… motivation and involvement in learning activities" (Udovic et al., 2002, p. 272) Ideal for: Confronting common misconceptions Advantages: Helps students build a mind map-like framework to interconnect prior knowledge and new ideas, which may lead to rectifying their own misconceptions. Challenges: Requires prior knowledge of misconceptions in order to develop activities that will confront these common misconceptions. Requires a lot of preparation.	Allen and Tanner (2005); Udovic et al. (2002)

Metacognitive teaching

The fourth active learning approach that has been investigated in Science and Mathematics is through metacognitive teaching. Mejia and Monterola (2015) investigated the effects of an intervention called Metacognitive Group Discourse to conceptual understanding of students on the topic nature of science. They engaged their students in metacognitive activities that require the students to reflect as a group in monitoring their own learning and the

learning of other group members (Mejia & Monterola, 2015). Metacognitive approaches or strategies refer to activities specifically designed for students to practice the skill of thinking about how they think so they can be aware of how they learn and acquire new information (Inclusive Schools Network, 2015). Mevarech and Kramarski (1997) have investigated a metacognitive technique to combat misconceptions in Mathematics. They call the intervention as the IMPROVE (Introducing the new concepts, Metacognitive questioning, Practicing, Reviewing and reducing difficulties, Obtaining mastery, Verification, Enrichment) method. This method uses self-questioning strategies in solving mathematics problems through the following metacognitive steps: (a) comprehension of the problem; (b) bridging ideas between the previous and the new knowledge; (c) applying appropriate strategies to solve the problem; and (d) reflecting on the processes to come up with the solution (Kramarski & Mevarech, 2003). Mejia and Monterola (2015) and Kramarski and Mevarech (2003) concluded that the metacognitive types of intervention develop independent learners and critical thinking skills.

Contextualised and blended learning

The fifth method of achieving active learning and student-centred instruction is the contextualised and blended learning in teaching Biochemistry developed by Macaulay, Damme, and Walker (2009). They used problem solving exercises, case studies and virtual subjects that present real life situations relevant to the students' specialisations to contextualise Biochemistry concepts to the later clinical practice of nutrition students. They presented the concepts in a blended curriculum by making use of different techniques and materials to enhance student learning such as online, on CD and face-to-face, in small or large groups and in tutorials, lectures, and laboratory classes. Other than being intellectually stimulating, this approach also assists students to apply and integrate concepts in biochemistry to understand metabolism and appreciate the importance of biochemistry to everyday life (Macaulay et al., 2009). Table 2.3 presents other useful contextualised and blended learning methods.

Table 2.3.

Useful contextualised and blended learning methods for science academics

Approach	Brief Description	Further Resources
Problem-based learning (PBL) and case studies (CS)	Allows students to think and work like scientists. A real-world problem is provided, and students resolve this problem in small groups using a learning cycle approach (e.g. the 5E, see Table 2.2). The progress of the group and the assessment are monitored by the instructor and/or a peer facilitator. PBL and CS enhance critical thinking of students (Andersen & Schiano, 2014; Kong, Qin, Zhou, Mou, & Gao, 2014) Ideal for: Developing skills in writing, organising thoughts and searching for relevant literature. Advantages: Helps students apply and connect previously learned concepts to a real-world context while developing skills of being a self-directed learner. Challenges: Effort and time required to generate meaningful and engaging problem-based learning or case studies.	Prince (2004); Allen and Tanner (2005); Michael (2006); Ambruster et al. (2009); Eison (2010); McFarlane (2015); Andersen and Schiano (2014)
Peer-led team learning	The lecturer solicits the help of the best students from the previous semester's class to serve as peer facilitators in small group discussions. The lecturer provides the materials to be used by the peer facilitators and guides them throughout the process. This method enhances students' conceptual understanding and attitude towards science (Bramaje & Espinosa, 2014; Tenney & Houck, 2004) Ideal for: Developing interpersonal skills and communication among students Advantages: Students are more comfortable discussing ideas in the small informal group setting. Peer facilitators get a better understanding of the key concepts and are able to improve their leadership skills Challenges: The most challenging part of this technique is recruiting peer facilitators, as well as the time and effort to craft materials that cater to the needs of the students.	Allen and Tanner (2005); Gosser, Cracolice, Kampmeier et al. (2001); Gosser, Strozak, and Cracolice (2006); Kampmeier, Varma-Nelson, Wedegaertner, and Wamser (2006)

Flipped classroom

The sixth active learning approach that has been investigated in higher education is through flipping the classroom. Bishop and Verleger (2013) describe a flipped (or inverted) classroom as "an educational technique that consists of two parts: interactive group learning activities inside the classroom, and direct computer-based individual instruction outside the classroom" (p. 6). In this active learning approach, students study materials of the course (e.g. video lectures, readings assignments, research assignments, etc.) individually, outside of class.

During class time, students work through the course materials by employing one or more of the approaches mentioned in tables 2.2 and 2.3. The role of the lecturer is to facilitate the learning process by assisting students while they work on the course materials. This method is found to improve learning gains and academic performance of students (Burke & Fedorek, 2017; Foldnes, 2016). Flipped classroom also enhances student engagement (Moravec, Williams, Aguilar-Roca, O'Dowd, & Wakimoto, 2010), which consequently result to improved learning outcomes (Klem & Connell, 2004; Krause, 2007). The flipped classroom approach to teaching is further explained in Bishop and Verleger (2013), Burke and Fedorek (2017), Moravec et al. (2010), Bergmann and Sams (2012), and Foldnes (2016).

Problems to be managed in implementing active learning in large classes

While the implementation of active learning in large class teaching is highly encouraged, Haack (2008) found out that just joining classroom activities may not be sufficient for students to attain deep learning. For active learning to be an agent to achieve deep learning, teachers need to "organise the learning environment as a scaffold across the entire curriculum" (Farrell, 2009, p. 2). That is, students should be exposed to an active learning curriculum that teaches them to be independent, self-directed learners. There are four major obstacles to establishing an active learning curriculum: the difficulty of covering curriculum, time required to prepare materials, training instructors in pedagogy so that they are comfortable moving away from lecturing, and if the lecturer is superficially concerned about student course evaluations impacting on tenure or promotion applications (Faust & Paulson, 1998; Henderson & Dancy, 2011; Jacobson, Davis, & Licklider, 1998; Knight & Wood, 2005).

Difficulty of covering curriculum

The first obstacle to incorporating active learning into the curriculum is how much of the required content can be covered in a term. Instructors can find it difficult to cover enough content because they are engaging their students with different activities that take a lot of class time. Hence, the deciding factor is "either teach more material and have students learn less, or teach less material and have students learn more of it" (Faust & Paulson, 1998, p. 17). The natural leaning of most academics in content-dense STEM disciplines is to choose the former rather than the latter because they believe that this level of detail is a prerequisite to acquiring knowledge in higher level science courses (Henderson, Dancy, & Niewiadomska-Bugaj, 2012). Active learning, however, is not only applicable to activities during class time but can also be incorporated into assignments or other activities that are done outside the classroom. Thus, the

instructor need not cover everything in class, but the students are still able to cover the topics in the course by accomplishing the assignments and other activities.

Time required to prepare materials

The second obstacle to integrating active learning is the time required for preparing active learning materials (Faust & Paulson, 1998; Kober, 2015). Teaching a course for the first time will require a lot of work in developing materials if active learning is to be integrated in the classroom. However, often materials are already available on the Internet. The role of the lecturer is to contextualise these materials to suit the students. If the instructor teaches the same course every term, s/he need only collect the active learning materials for the course once. In fact, active learning activities need not always be complex and sophisticated (Faust & Paulson, 1998). Active learning spans the simplest to the most complex activities presented in section three of this chapter that the lecturer can integrate into the curriculum.

Training instructors in pedagogy so that they are comfortable moving away from lecturing

The third obstacle is that instructors are already comfortable lecturing. Hence, implementing active learning methods can seem intimidating (Faust & Paulson, 1998; Kober, 2015). The primary concern of academics is losing control of the class when they implement active learning methods (Faust & Paulson, 1998) because most of them have limited or no background on classroom management. In addition, they think that students will react negatively when they implement something that is not usually done in their other science classrooms (Henderson et al., 2012; Seidel & Tanner, 2013). Most of these academics have been educated using traditional lectures and their belief is that students will learn better the way that they were taught. Thus, they are reluctant to infuse active learning into their classroom. The possible solution to this problem is to integrate active learning gradually into their teaching every term instead of abruptly changing the whole curriculum to an active learning one. In this manner, they will prepare themselves as well as the student community for embracing the active learning curriculum later.

Lecturer is superficially concerned about student course evaluations impacting on tenure or promotion applications

The fourth obstacle to implementing active learning is the fear of getting low student evaluation of the course, which is being used by the lecturer to secure a tenure position or to be promoted (Kober, 2015). In this case, instructors choose to stick to lecturing rather than

implement active learning methods because lecturing is already tried and tested. However, although student evaluations are designed to measure satisfaction with the course, students can also be influenced by factors that do not relate directly with the quality of their learning experiences (Lodge & Bonsanquet, 2014) but to the personality of the lecturer such as friendliness and good communication skills (Tsinidou, Gerogiannis, & Fitsilis, 2010), physical attractiveness (Freng & Webber, 2009), and charisma (Zhao & Gallant, 2012). Moreover, the validity of some student evaluation instruments are not well established (Lodge & Bonsanquet, 2014). Thus, the data collected from the instruments have questionable reliability and do not substantially account for the ability of the lecturer.

To drill down deeper, not all studies regarding active learning in large class cohorts have yielded positive results. In a broad study involving students in major universities across the United States, Andrews, Leonard, Colgrove, Kalinowski, and Klionsky (2011) examined the correlation between active learning approaches and students' learning outcomes in the topic of natural selection. Results suggest that there is no association between the use of active learning approaches and the learning gains of students. Andrews et al. (2011) also noted that participants in their study are 'typical' biology instructors, who have very limited training on science education. This observation led them to conclude that the success of the approach is not associated with 'active learning' methods per se, but rather with the level of educational experience and skill of the teacher of the subject. It is expected that these education researchers have a greater command of the chosen active learning strategy and are more likely to ensure a positive result (Michael, 2006). Unfortunately, this indicates that while active learning strategies are needed and are very important, the quality of teaching training is also extremely important (Gibbs & Coffey, 2004).

Conclusions and Recommendations

Large class teaching poses many challenges to science academics. However, it seems it will be a continued response to financial pressure in many higher education institutions. The literature suggests that one of the best things that academics can do to improve learning outcomes in a large class setting is to infuse active learning approaches into their teaching practice (see Freeman et al., 2014). There is abundant evidence that integrating active learning strategies into large class cohorts improves academic achievement and student engagement and using them more frequently will then develop the students to be self-directed or independent learners. However, there is no single definitive active learning approach that will lead to the realisation of these outcomes, given the wide variety of educational contexts. Different

strategies need to be trialled and carefully evaluated in each situation. A review of education literature concludes that active learning will only be effective if teachers are trained to apply it; it must be well structured and implemented consistently within the curriculum with clear expectations. However, there are still obstacles in scaffolding active learning in the entire undergraduate STEM curriculum, such as content-heavy courses, teacher education experience, and time required for preparation.

To overcome these obstacles in a large class context, the literature suggests the following. Instead of covering all topics during class time, the more straightforward topics should be introduced in an assignment, group projects or other activities done outside the classroom. This argument aligns with the work of Dall'Alba and Bengtsen (2019) on 'dark learning' that students actively learn 'when we do not see them' and 'when we do not hear them' (p. 11). A base group can be assigned by the lecturer at the start of the semester, so that students will work with their peers in small groups outside the classroom.

Active learning materials should be used and adapted from sources like the Internet. A lot of active learning resources for large class cohort is freely available online. The role of the lecturer is to contextualise these materials based on the requirements of the course as well as the learning profile of the cohort. Other lecturers in the same or similar course need to be collaborators in integrating either simple or complex active learning methods into the entire curriculum, so that they can learn from each other and help improve their teaching practices in a large class cohort.

Active learning can be integrated into the curriculum gradually instead of abruptly. Lecturers can choose to implement active learning for a small proportion of the semester until such time that they are comfortable to fully apply active learning into their large classes. The student course evaluations need to be read carefully in order to use them as critical tools to improve teaching instead of just judging the ability of the lecturer.

Finally, lecturers can attend education conferences or fora on how to efficiently and effectively implement active learning approaches in large classes. Universities can also offer professional development opportunities to help academics trial new approaches.

Chapter 3

Understanding the pedagogical and curriculum design practices of Australian STEM academics (Part 1)

As higher education transitions from an exclusivist to a more accessible endeavour, class sizes are continuously increasing, prompting academics to explore different strategies to infuse quality learning into their practice. Using the Productive Pedagogy and Technological, Pedagogical Content Knowledge frameworks, I explore the current practices of Australian academics in order to understand how science, technology, engineering, and mathematics (STEM) academics cope with the mass education context, and whether there are specific blocks to the introduction of active learning into these classrooms. I utilised inductive thematic analysis to identify the themes underpinning their pedagogical and curriculum design practices. These data indicated that these academics: (1) consider themselves to be, and are, traditional teachers, (2) believe that their students will learn better the way that they were taught at university, (3) are trying to shift their teaching from traditional to non-traditional, (4) practice reflective teaching, (5) collaborate with their colleagues to design the course curriculum, and (6) adapt the curriculum to suit students' knowledge, needs, and attitude towards learning. These findings suggest that these pedagogical and curriculum design practices are primarily influenced by the academics' own presumptions and educational beliefs on how the specific discipline should be taught. However, although they have adjusted their educational methods based on contextual factors such as large class sizes and resource constraints, the teaching remains predominantly traditional. Engagement in professional development and exposure to new teaching initiatives appear to be influencing some academics to shift their teaching towards a more active and student-centred focus, but this is not the complete story, and the lack of formal education training is holding many STEM academics back from fully engaging with current pedagogical best practice. The findings in this study are not only true for the STEM disciplines, but also more broadly to any higher education disciplines.

Keywords: active learning, teaching practices, assessment practices, pedagogical practices, curriculum design practices, productive pedagogy, technological pedagogical content knowledge

Introduction

Active learning is one of the best strategies to ensure that classroom activities lead to long term learning (Meyers & Jones, 1993), especially in subjects that require critical thinking and problem solving skills, such as in science, technology, engineering, and mathematics (STEM) disciplines (Armstrong et al., 2007; DeHaan, 2005; Handelsman et al., 2004; Smith et al., 2005; Zoller, 2000). However, active learning is often only minimally incorporated in most higher education classes (Aspland, n.d.; EYLF Professional Learning Program, 2010). This situation will not be improved unless we can understand why this is the case. One difficulty appears to be implementing active learning strategies in large classes (Fildes et al., 2015). This is a major challenge in most Australian universities (e.g. Cavanagh, 2011; Davis et al., 2012; Fildes et al., 2015; Rowland et al., 2012; Rowland et al., 2011; Verkade, Lodge, Elliot et al., 2017). For example, budget constraints can cause small group tutorials in large service classes to be phased out and replaced with large class 'tutorials,' which can limit the implementation of active learning. Complementary to this, a lack of pedagogical training could be contributing to poorer educational design decisions (Andrews et al., 2011).

In this chapter, I have surveyed the current teaching and assessment practices of Australian biochemistry and molecular biology (BCMB) academics to examine issues of curriculum design within a group of academics in a single discipline, across a range of universities. I present the recurrent and unifying themes of the pedagogical practices of these academics, so as to better understand the blocks that are limiting the introduction of pedagogical best practice. I use this as an example of the wider issues that operate across Australian higher Education.

Are large classes a block to innovation?

Even though large class sizes can present an obstacle to active learning, many academics across the world are exploring novel ways to integrate active learning into these settings, such as "bookending" or asking a focused question every 10 or 20 minutes with a 5-minute summary at the end of the session, "on-the-spot feedback," learning cycle [e.g. 5E - engage, explore, explain, elaborate and evaluate (Ebert-May, Brewer, & Allred, 1997)], peer-led team learning, problem-based learning and case studies, workshops, and collaborative and cooperative learning (Allen & Tanner, 2005; Ambruster et al., 2009; Armstrong et al., 2007; Waldrop, 2015). Integrating such strategies into large class teaching has led to higher achievement, better understanding of concepts, and a more positive attitude towards the sciences among students (Allen & Tanner, 2005; Ambruster et al., 2009; Armstrong et al.,

2007; Waldrop, 2015). A detailed description of these strategies for active learning in large class teaching is discussed in the previous chapter.

In Australia, some biomedical science academics have trialed the integration of active learning into their large classes. For example, Macaulay et al. (2009) improved teaching by contextualising concepts with blended learning using case studies, problem solving exercises, and virtual subjects representing real life situations were introduced to the class. Thematic teaching can also achieve active learning and student-centred instruction in biochemistry. Rowland et al. (2011) developed 'concept lens' diagrams in presenting concepts to a large class size to develop deep and contextualised understanding of key concepts in Biochemistry that will help them to have better grasp of concepts in their field of specialisation.

Other biomedical science academics in Australia are finding ways to integrate active learning in practical laboratory classes, rather than in lecture classes. The aim was to do away with the "recipe" or "cookbook-type" laboratory experiments and to introduce more interactive and research-driven experiments (Rowland et al., 2012). The most common improvement to laboratory practical classes is the use of inquiry-based learning, as it has been shown to improve conceptual understanding and process skills of students (Bugarcic, Zimbardi, Macaranas, & Thorn, 2012; Cook, Snow, Binns, & Cook, 2015; Prasad & Turner Mark, 2011; Rowland et al., 2012). Although there is abundant evidence of the important place that active learning has in quality pedagogical design, there still appears to be a deficit in the application across the Australian higher educational landscape.

The research study reported in this chapter examines the pedagogical practices of a broad cross-section of BCMB academics to better understand the range of approaches to teaching in a single field, and to understand how the pedagogical design decisions are being made. Specifically, it aims to identify the impediments to implementing improved teaching practice focusing on a single science discipline in Australia. Science students comprise 11% of the Australian university offers made in 2017 (Australian Government Department of Education and Training, 2017), so this sample represents the teaching provided to a large cohort of students across higher education institutions in Australia.

In this chapter, I asked very broad questions about decisions relating to curriculum design, mode of delivery, and assessment practices to understand fully the academics decision-making process. I identified what blocks might be preventing academics embracing innovative teaching approaches, for example lack of pedagogical knowledge, lack of resources, or other constraints.

Methods

Data from four sources were analysed: face-to-face interviews, an online survey of the teaching and assessment practices, classroom observation, and collection of the documents utilised by those academics who were observed. The interview questions (Appendix 1), survey questions, and the classroom observation protocols were anchored on two established frameworks – the Productive Pedagogy (PP) and Technological Pedagogical Content Knowledge (TPACK). PP is a useful framework for instruction because it presents a "comprehensive understanding of the essence of teaching" (Sun, 2013, p. 1651) based on intellectual quality, connectedness, recognition of difference, and supportive classroom environment (Gore, 2001; Mills, Goos, Keddie et al., 2009). TPACK was designed to identify the degree of integration of content, pedagogy, and technology needed by the lecturer to effectively teach in a technology-enhanced classroom (Graham, 2011; Mishra & Koehler, 2006; Thompson & Mishra, 2007). Together, these frameworks describe quality teaching choices to represent a valuable reference point from which to understand the design decisions of these academics.

The Productive Pedagogy (PP) framework

The Productive Pedagogy (PP) framework (Figure 3.1) supports the delivery of a high quality education for all students, especially those who are coming from a disadvantaged background (Lingard, Ladwig, Mills et al., 2001; State of Queensland Department of Education and the Arts, 2004). It identifies four main essential dimensions of 'good' teaching: (1) intellectual quality, (2) connectedness, (3) recognition of difference and (4) supportive classroom environment (Gore, 2001). Although PP was primarily developed for K-12 basic education, there are also studies showing the application of this framework to university education (e.g. Alsharif & Atweh, 2010; Alsharif & Atweh, 2012; Gore, Griffiths, & Ladwig, 2004).

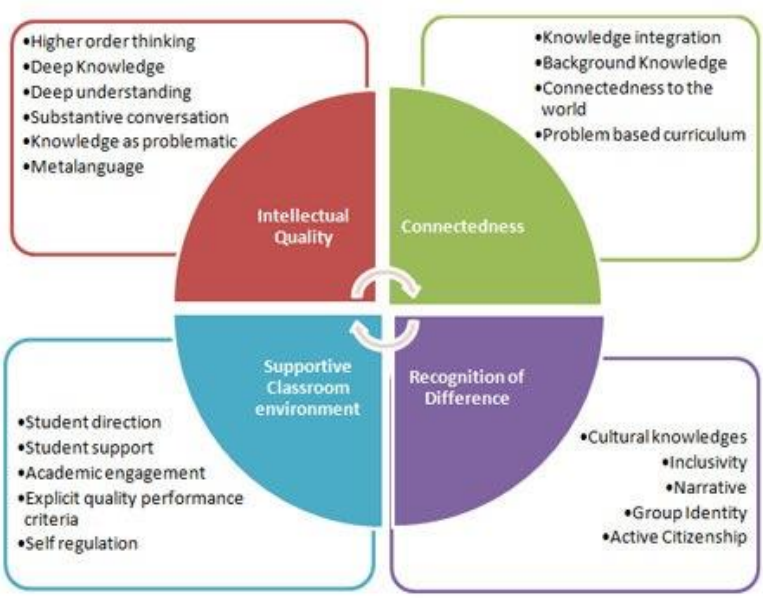
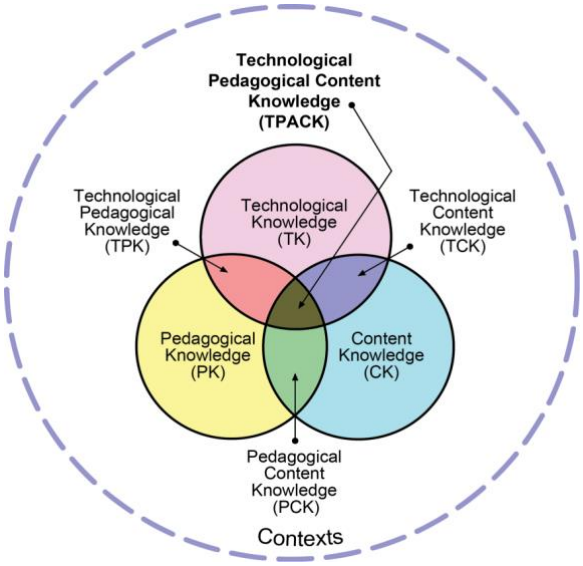


Figure 3.1. Components of Productive Pedagogy categorised into dimensions (Marsh, 2013)

Intellectual quality emphasises that all students should be equally provided with intellectually challenging work; hence, neither students' perceived academic ability nor "traditionally underachieving backgrounds," such as membership to low socioeconomic or indigenous groups, should foster learning prejudice (Darling-Hammond, 1997; Mills et al., 2009, p. 72; Newmann, 1996). Connectedness highlights the importance of increasing students' deep understanding of the content using meaningful learning experiences that will entail students to use higher order thinking skills (Darling-Hammond, 1997). Valuing and working with difference (or recognition of difference) acknowledges diversity in a learning environment, which presents to students the ability of power to raise acts of subordination and domination (Mills et al., 2009) and the effects of age, gender, race or ethnicity, and socioeconomic status to one's identity (Frankenstein, 1997; Gutstein, 2003). Supportive classroom environment recognises a type of classroom setting that gives students voice regarding the facilitation of the learning process; a classroom environment that manifests care, which breaks the power of inequities between teachers and students (Keddie & Churchill, 2003; Martino & Pallotta-Chiarolli, 2003). Appendix Table 2 shows the components of Productive Pedagogy categorised in their respective dimensions and the questions that I look into as I record my observations.

The Technological Pedagogical Content Knowledge (TPACK) framework

The Technological Pedagogical Content Knowledge (TPACK) framework (Figure 3.2) consists of seven constructs. The first three are independent: content knowledge, pedagogical knowledge and technology knowledge. The remaining four represent the overlap between these constructs (Thompson & Mishra, 2007). Table 3.1 outlines a detailed description of each of the construct of TPACK. These are the elements that I look into as I observe classroom discourse for one semester. The descriptions of the TPACK construct is further explained in Cox and Graham (2009).



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Figure 3.2. The TPACK framework

Table 3.1

Brief description of constructs in the TPACK framework from Mishra and Koehler (2006)

Construct	Description
Pedagogical Knowledge	Pedagogical knowledge (PK) refers to the understanding of teaching and learning processes and approaches that integrate educational aims, purposes, and values. The PK involves awareness matters concerning "student learning, classroom management, lesson plan development and implementation" (pp. 1026-1027). This construct also gives specific regard to the nature of target cohort of students, teaching techniques in classrooms, and means in assessing understanding of students.
Content Knowledge	Content knowledge (CK) refers to the understanding of the actual subject matter to be acquired or discussed. This construct encompasses "knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organise and connect ideas; and knowledge of the rules of evidence and proof (Shulman, 1986)" (p. 1026).
Technological Knowledge	Technological Knowledge (TK) involves the knowledge of computer hardware and operating systems, and the skills to use software programs like browsers, electronic mail, spreadsheets, and word processors. Moreover, it encompasses knowledge of installing and removing external devices, software programs and document creation and filing.
Pedagogical Content Knowledge	Pedagogical Content Knowledge (PCK) is the combination of pedagogy and content to form knowledge of how topics are structured, adapted, and offered for teaching. It does not isolate one from the other, thus, the equal attention to both the content and pedagogy.
Technological Pedagogical Knowledge	Technological Pedagogical Knowledge (TPK) is the knowledge of the alterations in teaching brought about by applying various technologies. It involves integrating components and applications of technologies to the teaching and learning environment.
Technological Content Knowledge	Technological Content Knowledge (TCK) refers to the understanding of the how content and technology are correlated. The newer technologies offer wide-range of representation and consequently, provide ease of directing these representations.
Technological, Pedagogical Content Knowledge	Technological, Pedagogical Content Knowledge (TPCK) poses as the foundation of good instruction integrated with technology and requires knowledge of the representation of applications using technologies, "pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones." (p. 1029)

Based on Graham (2011)

Participants and procedure for data collection

Australian academics (Table 3.2) who coordinate and/or teach BCMB at universities in Victoria (6), New South Wales (2), and Queensland (3) were interviewed. In these structured face-to-face interviews, academics were asked about their teaching and assessment practices (Appendix 1). The participants were mostly teaching into the second or third year of a three-year Bachelor of Science or Bachelor of Biomedical Science degree with some teaching into first year (e.g. Introductory Biology). In addition to their science qualifications, three of them have an education qualification. I conducted the interviews in a maximum of 1 hour at the participants' home institutions from December 2015 to March 2016. All interviews were audio-recorded and transcribed by an experienced transcriber.

Table 3.2

Profile of interview participants with pseudonyms

Academic	Qualification	Total years teaching experience	Years at current university	Year level currently teaching (undergraduate)	Type of classes taught
Archie	BSc (Hons) MSc DipEd*	29	11	2nd 3rd	Lecture Tutorial
Glenn	BSc PhD	25	25	2nd	Lecture
Cielo	BSc MSc PhD	23	23	1st 2nd	Lecture Tutorial Practical
Anna	BSc (Hons) PhD GCHE**	20	15	2nd	Lecture Tutorial Practical
Kenneth	BSc (Hons) PhD	20	13	1st 2nd 3rd	Lecture
Mark	BSc PhD	19	19	2nd 3rd	Lecture
Francis	BSc MS PhD DipEd*	17	16	1st 2nd 3rd	Lecture
Angela	BSc (Hons) PhD	15	14	2nd	Lecture Tutorial Practical
Michael	BSc PhD	11	5	2nd	Lecture
Leah	BSc (Hons) PhD	10	10	2nd 3rd	Lecture
Desiree	BSc (Hons) PhD	9	9	1st 2nd 3rd	Lecture Practical

*DipEd – Diploma of Education, **GCHE – Graduate Certificate in Higher Education

A 30-minute anonymous free-response survey was constructed in response to the interviews and was sent distributed online via SurveyMonkey to other academics across Australia from July to December 2016, with 8 respondents. In addition, I observed the 2nd year Biochemistry and Molecular Biology class for one semester of 2015 at a university in Melbourne, Australia using PP classroom observation protocol by Mills and Goos (2007) (Appendix Table 2) and the descriptions of the TPACK constructs according to Cox and Graham (2009). Lecture slides, tutorial slides and worksheets, and assessments were also examined. Rather than being a comprehensive survey across a very large number of academics, this study aimed for a qualitative approach using long and detailed interview answers from academics spread across different universities but representing closely related disciplines, biochemistry and molecular biology. The profiles of academics who took part in the classroom

observation are outlined in Table 3.3. Two academics from this institution, Archie and Angela, were selected to take part in both the interview and the classroom observation, as both independent of the study, and present at the hosting university. This allows triangulation of their claims during the interview.

Table 3.3

Profile of classroom observation participants with pseudonyms

Academic	Qualification	Experience in teaching in general	Years at current University
Archie	BSc (Hons) DipEd* MSc	29	11
Nelson	BSc (Hons) PhD	21	16
Angela	BSc (Hons) PhD	15	14
Catherine	BSc (Hons) PhD	18	10
Sally	BSc (Hons) PhD GCHE**	8	1

*DipEd – Diploma of Education, **GCHE – Graduate Certificate in Higher Education

Procedure for data analysis

I analysed interview transcripts through inductive thematic analysis together with an experienced independent inter-rater (a PhD candidate in education) to identify codes and categories/themes, followed by a discussion to identify common themes. Braun and Clarke (2006) defined thematic analysis as “a method for identifying, analysing, and reporting patterns (themes) within data” (p. 79). The PP and TPACK frameworks were used to code the pedagogical and curriculum design practices of academics. Inductive themes, on the other hand, were generated based on Pratt’s (1992) view that the "study and practice of teaching is grounded in our conceptions. There can be no neutral ground from which to understand another person's teaching" (p. 204). Having said that, I also acknowledge that in any qualitative study, there could be multiple interpretation of transcripts because “the interpretative practice of making sense of one’s findings is both artistic and political” (Denzin & Lincoln, 1998, p. 30).

The inductive thematic analysis was done by careful reading and rereading of the interview transcripts until patterns and connections among the teaching and assessment practices of academics were identified. Codes on teaching and assessment practices were generated while reading the interview transcripts, which were later classified, categorised, and cross-referenced with the interview transcripts. Inductive themes were then generated based on

the codes, which were eventually categorised and merged based on the major emerging categories. This approach is based on Boyatzis (1998) and Braun and Clarke (2006). Table 3.4 shows how interview transcripts were coded and how inductive themes were generated.

Table 3.4

Sample coding of interview transcripts and generation of inductive themes

Interview transcript	Code	Category/Theme
"*In the third year where I've given a tutorial, I've tried to do a bit of reversing here. So, I go in again, but now I've got something like three or four questions from past papers or I've constructed and what I do is then break the class into two, three, four, depending on the groups. So groups of about five students and tell them and tell each of those groups, you will answer question one, you'll answer questions two, you'll do three, question four, then I give them fifteen minutes let's say to do that or a period of time to write out an answer.*"	Pedagogical knowledge	Trying out active learning and student-centred activities
"*If a student has certain disabilities I usually have on-on-one contact with that student and work out what their needs are and work out what potentially they need, you know, in terms of sometimes if it's a sight problem we might have to provide slides in a different format for them and materials in a different format.*"	Social support (supportive classroom environment)	Adjusting teaching to suit students' needs

I carried out the same analysis process on the data collected from the survey, classroom observation and collected documents. Using these qualitative methods, I identified the themes underpinning the teaching of BCMB by these Australian academics. The themes were classified into two major categories: (1) pedagogical practices and (2) curriculum design practices. The former is discussed in the first part of this chapter while the latter is discussed in the second part.

Findings

Theme 1: Australian BCMB academics consider themselves to be, and are, traditional teachers

Regardless of how many years of university teaching experience they had, a majority of the academics consider themselves to be traditional teachers. They employ direct instruction using teacher-centred methods in their classes (e.g. lecturing, 'chalk and talk' methods). They also reported that they employ objective-type assessment, such as tests in the form of true or false, matching type, or multiple-choice questions (MCQs). The shortest length of experience of academics in this study was five years, and most had more than 10 years, so it is certainly possible that newer academics may not consider themselves traditional or 'old school.'

When asked to describe a typical lesson in their lecture classes, most of them started saying that they are a 'traditional teacher' or an 'old school teacher.' Mark said, "*...with the lecture I guess I'm old school, I come in and I'm not expecting any interaction from the students.*" In addition, even though Francis has high school teacher qualification, he still considers himself to be traditional: "*... I'm more of a traditional type teacher where I'm using a PowerPoint presentation to deliver content.*" Anna agreed by saying that "…*typically in terms of the lecture I'm doing like traditional format lectures where we have to just convey information*." It seems that most of the academics stay in the lecturing comfort zone possibly because a majority of them lack pedagogical training to enhance their pedagogical knowledge. This method, however, is contested by education researchers to be ineffective in promoting interaction with the students and it does not support deep learning as well as active approaches (Bransford et al., 2000). Hence, the lecture method does not promote academic engagement (supportive classroom environment) and deep understanding (intellectual quality).

Classroom observation supported the academics' claims of traditional teaching methods as Angela and Catherine tended to deliver passive style lectures using the slides they had prepared. Sometimes they would ask questions, but the questions were a recall of facts or a simple true or false type. Angela and Catherine seem to demonstrate technological content knowledge by deciding how much of the content to put in each slide. Their approach, however, is still traditional because it does not promote intellectual quality as they only asked questions that will require lower order thinking. Archie, in contrast, incorporated different teaching strategies such as songs, simulations, historical trivia, practical applications of concepts, and careers in this discipline. These strategies appeared to promote interest from the students in a way that they focus their attention to the lecturer. Hidi, Renninger, and Krapp (2004) argued that a focused attention indicates interest. These observations validate Archie's claim that he does not consider himself a traditional teacher, not only because he has a high school teaching experience, but also because he "… *was a trained teacher because I had been through teachers' college.*" Archie seems to demonstrate a good pedagogical content knowledge as he taught the content using a wide range of teaching approaches that promote academic achievement (supportive classroom environment) and knowledge integration (connectedness).

When asked about their typical assessments, the majority described objective-type assessments, particularly MCQs. For example, Michael said, "…*we at this point are using only multiple choice on our mid test and exam.*" Leah said that they also are incorporating free response items, but this is very limited: "…*the final exam is a lot of multiple choice still but [with] 5 short answers*." Leah's reasoning for the MCQs is "*definitely size of the cohort.*" Anna

also said that the reason for giving multiple choice questions is "…*the way that the units are structured in terms of having exams.*" It appears that the assessment decisions of academics are greatly influenced by class size (~400 to 1000 students) and departmental practice.

When asked if they are happy with the way they have written their multiple-choice questions, Leah said, "…*I've done courses in the design of multiple-choice questions, so I think they're done quite well.*" In contrast, the majority of the academics state that they are not confident in the quality of their questions, even if they have attended workshops on MCQ design. Angela remarked that, "…*I've set some really bad multiple-choice questions. It's not easy [even if] I've been to the workshops.*" One possible reason to this is length of exposure to workshops, and a willingness to learn – some academics take the information on board better because they are more keenly interested in educational assessment and pedagogy, or perhaps they have more theory in which to embed this learning. Academics who attended more workshops and are more interested in educational assessment would most likely acquire higher degree of pedagogical content knowledge to be able to write MCQs that will encourage intellectual quality.

Examination of the mid-semester and final exams set by the observed academics clearly shows objective-type assessments being utilised. For example, in the final examination, the majority of the questions were MCQs and fill in the blanks with a few matching type questions. Only a few items were devoted to free response. The mid-semester test consisted of MCQs only. Although there was an attempt to integrate *application* and *analysis* questions into the MCQs, most of the MCQs and fill in the blank questions still fell under *knowledge* and *comprehension* in Bloom's taxonomy of learning (Huitt, 2011). The few free response questions, on the other hand, could be classified as *application*, *analysis*, and *synthesis*. *Knowledge* and *comprehension* questions only promote lower order thinking while *application*, *analysis*, and *synthesis* questions promote higher order thinking and reasoning, and the use of these should be highly encouraged in university assessments (Bush, Daddysman, & Charnigo, 2014). It seems likely that their assessment decisions were due to their being traditional teachers or due to the lack of pedagogical content knowledge in constructing MCQs that will promote intellectual quality.

Theme 2: Australian BCMB academics are trying to shift their teaching from traditional to non-traditional

Being highly aware of students' prior knowledge and needs, some academics are trying to complement this traditional teaching style by experimenting with the way they teach and

assess students, integrating innovative strategies and performance-based/authentic assessments into their teaching. Participants reported that they are trying out active learning and student-centred activities in their classes.

Mark, for instance, trialled different ways of conducting tutorials until he found the best fit for his students: "*In my tutorial I've had several styles and I've only found one of them satisfactory.*" What he found to be effective was "*to do a bit of reversing"* – instead of going through how to answer questions, he let the students discuss the questions in groups first, before discussing it in class: "*I've got something like 3 or 4 questions from past papers or [that] I've constructed and what I do is then break the class into… groups of about 5 students, and …tell each of those groups, you will answer question 1, you'll answer question 2, you'll do 3, question 4, then I give them fifteen minutes … to do that or a period of time to write out an answer.*" This strategy seems to elicit interaction with the students and could promote deeper learning as the students are answering analytical questions. Mark seems to demonstrate a good grasp of pedagogical content knowledge as he trialled various methods of conducting the tutorials that appear to promote academic engagement (supportive classroom environment) and substantive conversation (intellectual quality) because it persuades students to interact and discuss with one another.

In addition, Leah used movie clips to introduce a topic in her lecture classes. These movie clips require students to think to deduce the concepts: "*[In my lecture,] I normally have a couple of movies and they're more abstract movies - they're not always exactly on what it's on. It might just be more the concept.*" In this way, students not only enjoy the movie, but they are also required to think critically. It seems that Leah demonstrated technological, pedagogical content knowledge by using movie clips as a springboard for students to deduce scientific concepts. Her method also seems to embody the constructs of connectedness as it tries to apply scientific knowledge to a real-life context.

In Kenneth's case, he tried organising the course into different approaches to maximise the learning experiences of students: "*…I've structured the courses that I teach so that we teach using a number of different methodologies. There's face-to-face lectures, we also have workshops, which are interactive where the students are given a series of questions they work on in small groups.*" He further described how they run the workshop: "*… we give them a series of questions and they work within their small group to come up with the answers to those questions and then present it to the rest of the group.*" It seems that these workshops give students the opportunity to interact with, and learn from, one another. Kenneth seems to exhibit a good grasp of pedagogical knowledge as he made an effort to organise the course in such a

way that he can maximise the learning experiences of students. His method seems to embody the elements of a supportive classroom environment as it promotes academic engagement and student direction of activities.

Michael shows another example of reform in teaching his course. He said "…*I've been doing a lot of development with this unit and the way we are teaching these units.*" He even added that he is collaborating with his counterparts in the different campuses to improve the way they teach BCMB in the university: "*...[we] work together very tightly and together [we] developed a new way to teach that we've completely implemented this year.*" He further described what they have developed to be "*...online learning modules, which are packages… containing the content or describing the content of each chapters.*" Michael further describes the parts of the online learning module: "…*has a certain title, covers a certain topic, gives the learning outcomes, gives a lot of video resources that provide overviews and context and detail and then we have… approximately up to 20 pages of guiding questions.*" Aside from the learning modules, Michael also mentioned that they are trying "…*partially flipping the classroom.*" He described it as partial flip because "*...we are giving… every student the chance - who does not do the work at home - to follow when they come in class or when they watch the lecture or the class online*." He said that this method has had good reception from the students "*…the clear majority of students said that this learning approach and learning module you've produced is great*." These online learning modules seem to encourage independent learning and perhaps promote deeper understanding of concepts because the students are deducing concepts themselves with the help of the modules. Michael seems to exhibit a good grasp of technological, pedagogical content knowledge as he implemented a wide range of approaches into his classroom to give the best possible learning experiences to his students. His method appears to promote student direction of activities and self-regulation (supportive classroom environment) as it empowers students to study the materials on their own phase and schedule.

Cielo is also doing some reforms in her teaching by trying out different approaches: "*I've been trying to do more different things, trying to make them more interactive so I use a variety of things*." She further describes some of the things that she is doing in her classes: "*...I use the Poll [because] I often put questions up in class. I've been trying to introduce some case studies that we do throughout the lectures as well.*" In addition, she said she has "…*been trying the think-pair-share process quite a lot.*" As a conclusion, she reiterates that "…*I guess I'm at the point of trying lots of different things at the moment and trying to work out… what I would like to do.*" It seems that Cielo demonstrated technological, pedagogical knowledge as she attempted to integrate online polling activities with various methods such as case studies and

think-pair-share. Cielo's approach to teaching appears to encourage substantive conversation (intellectual quality) as students discuss with their peers and connectedness to the world (connectedness) as students work on real life problems.

The group of academics who participated in the classroom observation seem to be on the same page as the academics who participated in the interviews. The observations of what they are doing inside the classroom supports that they are also trying to shift from traditional to non-traditional teaching. For instance, with the aim of engaging her students, Sally utilised a variety of instructional strategies to deliver the subject matter: (1) debate-like discussion on which is a better candidate for genetic material – protein or DNA?; (2) analogy of a genome to a library; (3) trivia integrated to the lesson, such as the human genome project and Dolly the sheep; (4) quick concept check by showing a diagram and asking what is wrong with it; and (5) demonstrating how to search gene sequence databases. These strategies seem to elicit interest from the students because it catches the attention of students. Hidi et al. (2004) argued that a focused attention is an indication of interest. Sally seems to demonstrate a good grasp of pedagogical content knowledge by implementing teaching strategies that will enhance the understanding of content. These strategies embody connectedness to the world (connectedness) because it exposes students to real-life applications of scientific concepts.

Nelson also used a variety of teaching techniques in his class: (1) integrating trivia into the lesson about blood groups and obesity; (2) showing interesting videos like anime-themed blood groups and the Fold-it Game, which shows how online multiplayer gaming is used in researching HIV, cancer, and other diseases; (3) using analogy in teaching, like the human hands to illustrate chirality, or comparing the groups of amino acids to a human family – they are related, but they have different characters; (4) using improvised materials to show how polarised light interacts with biomolecules; and (5) the use of a ball and stick model to show the geometric features of proteins. These strategies appear to promote interest with students in his large class. Similar with Sally, Nelson seems to demonstrate a good grasp of pedagogical content knowledge when he implemented teaching methods that enhances conceptual understanding of the students.

Interestingly, when thematically analysing the assessment documents of the group of academics who participated in the classroom observation, it seems they still employ traditional objective-type assessments in their subject. As mentioned in theme 1, the structure of the mid-semester and final examinations are mostly MCQs with a few matching type questions, true or false, and a limited amount of free response. Based on these observations, it is apparent that these academics prioritise reform in teaching, but not in assessment, possibly also due to the

constraints of large class sizes, usually 400+ in these universities, may impact on this decision. It is also possible that these academics might just lack the pedagogical knowledge to revolutionise their assessment methodologies.

Theme 3: Australian BCMB academics believe that their students will benefit from their learning experiences that are similar to their own university education

With limited pedagogical qualifications, some academics imitate the teaching and assessment practices of their own teachers from when they were undergraduates. Some BCMB academics discussed their experiences as a student, commenting on which teaching and assessment technique worked well for them and which did not. These experiences were also given as a reason for pursuing a particular teaching approach or assessment decision.

For instance, Archie believes that it is better to have only one assessment for the whole semester because students "…*do better under final exam conditions*" rather than giving two mid-semester tests where most students do not take it seriously. He even adds that "...*[it] is how I went through, purely final exam none of these wishy-washy mid-semester tests.*" Moreover, it is apparent that Archie thinks that students in the past learned better because they attended lectures – hence he talks about his frustration about present day students who do not attend lectures: "…*these days at the end of a course sometimes you're down to 20% of people in the whole thing that's a bit, personally insulting to me.*" But then again, he also says that "*I've got used to this new generation who do learn from online resources.*" Archie seems to recognise that online resources can be useful but feels that students would still understand better and possibly achieve more highly if they attended lectures. This point of view seems to contradict the notion that academics who have more pedagogical knowledge would embrace various learning environments where students can learn. In this case, Archie's thinking of a learning environment appears to be limited to the four corners of the classroom only, which does not support the elements of valuing and working with difference.

Likewise, Angela reported that she thought students learned better during her time as an undergraduate student because the education system gave more responsibility to students – hence she wanted that system to be adapted to the present time: "*I'd love to see a system I suppose where we go back to giving more responsibility back to students rather than the teacher.*" But then again, she also adds: "…*but you fall into it and one of the reasons you tend to try to do everything you possibly can to try and enhance the learning of the experience.*" With her teaching, it is apparent that Angela really wants to give more responsibility to the students. In most of her lectures, she would always remind students to look up definitions of

unfamiliar terms; otherwise, it would impact on their study of Biochemistry. Moreover, whenever she shows an equation (e.g. the Michaelis-Menten equation) in her lectures, she would not give examples on how to use or interpret it, but she will include them in the tutorial – hence students need to figure out how to use and interpret the equation themselves. It appears that Angela wants to encourage independent learning with her students. This point of view of Angela seems to manifest limited pedagogical knowledge because university education is a shared responsibility between the student and the academic. The academic's role is to provide meaningful learning experiences to give better learning outcomes for the students.

Archie and Angela, however, seem to take the view that the evolving nature of university students should still involve classroom participation. There is a great deal of evidence that what worked for students 30 or 40 years ago is often not as effective for this new generation of students (Biggs & Tang, 2007). Professional development in the changing nature of higher education would help bridge this gap.

Theme 4: Australian BCMB academics practice reflective teaching

Interestingly, having limited educational qualification does not appear to have limited reflective teaching in these academics. Most of the participants appear to reflect on their teaching and assessment practices in relation to student learning. This was demonstrated by the participants saying that they adapted pedagogy as a result of reflecting on past experiences. They evaluate what worked and what did not work, and further considered why it did not work. Moreover, the academics are reflective about students' attitudes towards learning, the reasons students do not get the most out of the course, and worse, why some are failing.

For example, Angela shared that she changed her teaching "…*in response to some student feedback."* She said "*[The students] were talking about how they quite like some questions thrown in using [a polling software]."* She thus started using online polling software because she noticed that "*…if I do ask any questions the students [just] sit there but the [polling software] thing I think that was a way of breaking it up."* It appears that reading student feedback helped Angela in confirming which of her teaching strategies was appreciated by the students. This viewpoint of Angela also manifest that she is promoting student direction of activities (supportive classroom environment) by considering the feedback of her students.

Kenneth, likewise, commented on how he and his colleagues currently teach BCMB. He said "*…if I could do something new this year it would be to redo the course taught a different way."* His reasoning was "*…I think we do it in a very old-fashioned way and that's why it's hard to incorporate blended resources."* As such, he said "*… I'd prefer to teach it a*

bit like I teach into the med program in which there's a scenario and then there's different concepts that relate to that and… I think you could incorporate those resources better." It seems that Kenneth thinks that students learn better in a blended learning environment, hence he wanted to restructure the course to make it more active, and give the concepts a more concrete context. Moreover, Mark is reflecting on how he can deliver the content better at the same time engaging his students in the discussion: "*…I'd like to know how can I (sic) change my style for the students to become more engaged.*" He even added that he is keen on *"…how can we do this more efficiently with better outcomes. I'm very interested to know.*" Clearly, Mark wants to enhance his pedagogical knowledge, so he can engage his students in the discussion and promote student direction of activities (supportive classroom environment).

Michael and Desiree, in contrast, have a different concern. Michael is more reflective about the importance of teaching the content than the method of delivering it: "*…I think we need to be there reinforcing [the students] to learn the structures. So, this is the special challenge I think to get them to do that."* It appears that Michael's concern was the appropriateness of a strategy to teach a particular concept; a manifestation that Michael has a good grasp of pedagogical content knowledge. Meanwhile, Desiree reflected on the difficulty of persuading students to engage in formative activities that are not graded: "*…I don't get them to do anything that's not graded because they won't do it."* It seems that Desiree does think that incorporating formative activities will help students understand the concepts better. This outlook of Desiree seems to demonstrate her pedagogical knowledge; she wants to incorporate formative activities to promote intellectual quality amongst her students.

Francis, on the other hand, is reflecting on how employment requirements for academics have changed over time because of budget constraints and how these affect teaching in the university: "*We're setting up a divide between research which is the cutting edge and discovery of the content that we're teaching and we're starting to employ people that are teaching out of textbooks, if this continues with this regime, universities in Australia will become TAFE's [Technical and Further Education institutions] and really, we're just becoming glorified high schools.*" It seems that Francis thinks that academics who are actively involved in scientific research are more effective teachers than academics who are not doing research. Francis' perspective seems to put much emphasis on content knowledge over pedagogical knowledge.

In the case of the group of academics whose classrooms were observed across one semester, it appears that the student evaluation helps them improve their teaching, as attested by Angela incorporating polling software in her lectures and tutorials. Archie also gave his

reflection about how students learn in the digital age and how he adapted his teaching to this context by letting students work on some materials online at the comfort of their own homes.

Discussion

Some academics want to shift to non-traditional teaching

Although some of the Australian academics in this study want to shift from traditional to non-traditional teaching in order to promote some of the elements of productive pedagogy into their classroom, they still consider themselves to be traditional teachers. This could be due in part to the common belief amongst academics that their discipline can only be taught in a certain traditional way (e.g. Becher, 1981; Lenze, 1995). This argument aligns with Shulman's (2005) signature pedagogies, which states that signature pedagogies are "the types of teaching that organise the fundamental ways in which future practitioners are educated for their new profession" (p. 52).

Another reason could be the lack of pedagogical qualifications or pedagogical knowledge. Because of the lack of exposure to education literature, academics are having difficulty addressing the major challenges in shifting to non-traditional teaching (e.g. Postareff, Lindblom-Ylänne, & Nevgi, 2007, 2008). In the literature, the frequent concern is that active learning classes may not cover the required course content (Faust & Paulson, 1998). It also takes time to prepare quality active learning materials, and, although there are some freely available, they still need to be contextualised to the course (Faust & Paulson, 1998; Kober, 2015). Some academics fear losing control of the class when they implement active learning strategies (Faust & Paulson, 1998); hence, most BCMB academics stick to lecturing because it is tried and tested. And finally, there is a fear of low student evaluations when academics implement something unusual (Kober, 2015). These challenges are addressed in Chapter 2 of this thesis.

Most of the academics lack pedagogical qualifications or pedagogical knowledge

Without pedagogical qualifications and with limited pedagogical knowledge, some academics simply imitate the pedagogical practices of their former teachers or teach according to their own presumptions and educational beliefs (Bain, 2000; Quinlan, 1999; Trigwell & Prosser, 1996; Trigwell, Prosser, & Taylor, 1994) instead of consulting the education literature on methods that will give the best learning outcomes for the students. Furthermore, it is still very common for institutions to place significant emphasis on the research experience, at the expense of the educational qualification or professional development in education, of those that

teach undergraduate subjects (Neumann, 2001). This can often leave academics ill-equipped to deal with the real and perceived challenges associated with shifting to non-traditional teaching. In this study, out of the fifteen interviewed and observed academics, only four have education qualifications. Although recent developments suggest that pedagogical expertise is now being considered in the hiring process of university academics (Geschwind & Broström, 2015), this demographic shows that many current teaching academics tend to have content knowledge and expertise in their own discipline, rather than pedagogical knowledge. Indeed, most higher education academics do not primarily consider themselves as teachers, but rather as a member of their own discipline (e.g. biochemist, molecular biologist) (Becher, 1989; Kember, 1997a), and this was appeared to be true for these academics, with the exception of Archie who specifically mentioned that he was trained as a teacher.

Professional development influences pedagogical decisions

Professional development (e.g. Postareff et al., 2007, 2008) and exposure to new teaching initiatives can influence the educational beliefs of academics (Bain, McNaught, Mills, & Lueckenhausen, 1998; Kember, 1997b). This has resulted in some of the academics in this study reporting in the interviews that they are shifting from traditional to non-traditional teaching by trying out active learning approaches into their large classes (generally 400 – 1000 students in the instances considered here). In 1992, Samuelowicz and Bain (1992, 2001) conducted a survey on the beliefs of academics about learning and teaching and identified five belief dimensions: desired learning outcomes, expected use of knowledge, students' existing conceptions, control of content, and directionality of teaching. However, when they repeated the study in 2001, new belief dimensions were identified that were more student-centred in focus, including the nature of knowledge, agent responsible for transforming knowledge, teacher-student interaction, students' personal/professional development, and interest and motivation. The changes in academics' beliefs about teaching and learning that occurred in this nine-year gap may be due to the influence of professional development, where academics earned more pedagogical knowledge.

Large class sizes can hinder pedagogical innovation

Contextual adjustments, such as the challenges of large class sizes and limited resources, influence the teaching approaches of academics (e.g. Mulryan-Kyne, 2010). In the present study, it appears that the pedagogical decisions of the academics are strongly influenced by large class sizes and resourcing issues, affecting teaching facilities, managing budgets, and

sessional staff requirements. They also spoke of the difficulty of having limited pedagogical knowledge in the specific challenges that large classes bring to assessment construction, teaching strategy, and classroom management in student-centred activities.

Teaching is often poorly recognised in universities

The reward system of higher education institutions also seems to influence the actions of the academics. Because research is commonly more highly rewarded than teaching (Bernstein, 2008; Harris, Farrell, Bell, Devlin, & James, 2008) academics allot significantly more time to doing research rather than preparing for their classes (e.g. Ballantyne, Bain, & Packer, 1999; Boyer, Altbach, & Whitelaw, 1994). Contrary to the popular assumption that academics who are actively involved in research will also be competent lecturers because they gain more content knowledge (e.g. Robertson & Bond, 2001), Ramsden and Moses (1992) and Hattie and Marsh (1996) have reported that high research outputs do not necessarily correlate with effectiveness in teaching undergraduate courses.

Although teaching is not seen as prestigious as research to many universities, this did not stop some of the academics in this study integrating innovative strategies, and developing tools and materials to assist them in their teaching. In fact, because some of them are reflective teachers, they have even restructured the entire course so that they can infuse active learning into their teaching. Bennett, Thomas, Agostinho et al. (2011) have even provided recommendations on how to assist academics in designing their own curriculum in the Australian context.

Student evaluations influence pedagogical decisions

A few of the academics reported reflecting on student evaluations to improve their teaching and promote some of the elements of productive pedagogies. However, student evaluation instruments are very often generic and fail to consider disciplinary differences in teaching approaches (Kolitch & Dean, 1999; Shulman, 1993; Uttl, White, & Gonzalez, 2017), and are well-known to be influenced by many irrelevant factors (Lodge & Bonsanquet, 2014). So simply changing the teaching approach into what students like may not be enough without evaluation of that teaching approach in context. Neumann (2001) even warned academics to take caution in using new teaching strategies from attending professional development, because blindly following a technology or an approach without reflection and without consideration of the context does not always give the best results. Andrews et al. (2011) even added that the success of a teaching approach is dependent on the level of education qualification or degree

of pedagogical knowledge of an academic rather than the active learning strategy per se. Thus, the quality of the education qualification of an academic is suggested to be the key to successful execution of a teaching approach (Gibbs & Coffey, 2004). In this case, it is reassuring to know that academics in this study practice reflective teaching, but they would still benefit from professional development in education, primarily because most of them lack teaching qualification. The literature has shown that further professional development opportunities would fill this gap and allow academics to fully embrace the best practice in university teaching (Gibbs & Coffey, 2004).

Conclusions and Recommendations

Despite identifying themselves as traditional teachers and having limited pedagogical knowledge, the academics in this study want to improve their teaching by infusing active learning strategies that will promote some of the dimensions of the productive pedagogy. Attendance to further opportunities for quality professional development in pedagogy and exposure to education literature is encouraged for them to be able to do this and would also help them to implement improvements that can cope with the challenging contexts of large class teaching and limited resources in higher education.

The academics expressed frustration that a lack of pedagogical knowledge limited their abilities to attack the problems that the modern university context was giving them (e.g. large classes and a broad student base). Hence, I suggest that the implementation of institutionalised guidelines for learning and teaching in higher education will help improve the teaching of STEM disciplines. Most higher education institutions (HEIs) have criteria for hiring lecturers who are teaching specialists and more importantly, one criterion growing in importance is pedagogical expertise. I suggest that heads of department should consider this in hiring all lecturers. In addition, the literature has shown that institutions should provide quality professional development opportunities on pedagogy for both new and seasoned lecturers. This should not simply focus on new technologies or the latest trend, but on the fundamentals of education and teaching that build up to allow great learning. Moreover, peer review of teaching should be introduced and used as a method of constructive critique to help academics shift from traditional to non-traditional (Klopper & Drew, 2015). Student evaluations should not only be updated to recognise disciplinary differences, but should also give importance to the voices of students. Finally, and perhaps most importantly, I suggest that HEIs should review their reward system and give teaching greater prominence so that academics will be able to give appropriate priority to preparing lessons that will give the best learning outcomes for the students. This is

likely to be the most important factor in improving teaching and learning in all of higher education, not just in BCMB or STEM.

Understanding the pedagogical and curriculum design practices of Australian STEM academics (Part 2)

Curriculum design practices

Apart from teaching and research, one of the many responsibilities of academics is to design the curriculum (Maki, 2004) from conceptualisation to implementation, evaluation and revision. Pring (1995) noted that course is different from curriculum: course refers to "a set of arrangement procedures and college syllabus which meet the relevant criteria (standards)" (p. 81), while curriculum refers to "the learning experiences (planned for the most part by the teacher) through which the course is put into practice" (p. 81). Designing the curriculum is an important task because it maps out the learning experiences that academics would offer to students for the entire duration of the semester (Stefani, 2008); and these learning experiences in the curriculum are a major factor in increasing engagement of students (Bovill, Bulley, & Morss, 2011). Klem and Connell (2004) and Krause (2007) argued that an increased engagement is always linked to improved learning outcomes of students. Because of the importance of curriculum design, researchers have started to examine how curriculum is designed in the Australian context (e.g. Bennett, Agostinho, & Lockyer, 2017; Bennett et al., 2011).

In most higher education institutions, the curriculum is primarily influenced by the 'culture' of the university (Stefani, 2008), which could be stated in a form of a mission-vision statement. The mission-vision statements provide an overview of the graduate attributes expected of students when they complete a degree in the university (Stefani, 2008). The role of academics is to align the curriculum to the institutional objectives for them to produce graduates with a certain set of graduate attributes (Maki, 2004). The literature offers a wide range of ways in which the curriculum is conceptualised (e.g. Light & Cox, 2001; Stefani, 2008). Here, I have selected as an example on how the curriculum is conceptualised, the work of Fraser and Bosanquet (2006) because of its relevance to the Australian context. Fraser and Bosanquet (2006) offered four classifications on how the curriculum is conceptualised in Australian universities: (1) "the structure and content of a unit (subject)" (p. 272), (2) "the structure and content of a programme of study" (p. 2.72), (3) "the students' experience of learning" (p. 272), and (4) "a dynamic and interactive process of teaching and learning" (p. 272), also referred to as co-construction of knowledge (Bovill et al., 2011) and co-creation in higher education (Dollinger, Lodge, & Coates, 2018).

There are many theoretical underpinnings and considerations that influence the practice of designing a curriculum. The focus of this study is to look into the curriculum design practices of BCMB academics to better understand the basis of their decisions while planning the curriculum. From the methodology and participants described above in this chapter, I have identified two additional recurrent and unifying themes describing the curriculum design practices of BCMB academics, and how these curriculum decisions are made.

Findings

Theme 5: Australian BCMB academics collaborate with their colleagues to design the course curriculum

It is a usual practice in Australian universities to team-teach courses, and this is exemplified by some Australian BCMB academics. They collaboratively decide on the content, delivery of the course and type of assessment to be employed. Participants reported that they collaborate with other academics on deciding on the scope and sequence of the content, the teaching approaches, the type and frequency of assessment, and the feedback. The team is led by a course coordinator/convenor who manages the planning, design and delivery of the course as well as selecting books and other resources, assessment of learning outcomes of the students, and the evaluation of the course.

For example, Mark said that the course prerequisites or "*…[what] we expect them to know [is decided upon] discussion with the coordinators and other lecturers."* Furthermore, according to Cielo, in cases when "…*students are having problems [about the subject]… [We] tell them to come and talk to the unit coordinator or bring it to our attention as well.*" The remark of Mark seems to give an overview of the content knowledge expected of academics as they plan the sequencing of the content as well as the objectives of the course. Cielo's statement, on the other hand, shows social support (supportive classroom environment) that academics extend to their students beyond the four corners of the classroom.

In some cases, collaboration becomes negotiation when the decision is made by agreeing with what is being presented by the course coordinator. For example, in a way how a course will be taught, Mark said "*Now what we did with the elective subject, and I was not responsible but the coordinator brought in for higher order learning, we broke that class into more 50/50 lectures and tutorials, where in the tutorials we brought in journal articles and taught the students how to understand and interpret those publications*." Mark's statement seems to give an overview of the pedagogical content knowledge expected of course

coordinators. It also seems that their pedagogical consideration is to improve or promote the constructs of intellectual quality.

Since some coordinators have been in the position for many years, their opinion is very much valued in the team because of the expectation that they have more pedagogical knowledge in teaching the course. So, in deciding about assessment, the academics defer to the more experienced academic like Archie who said "…*I've been a coordinator of science teaching for many, many years and many of those years I compared their multiple-choice performance against their written performance, the correlation was so close to 100%, it wasn't worth the difference*." Archie's comment seems to assert his support for multiple choice questions in assessing students based on his extensive experience in coordinating courses.

During my classroom observations, I noticed how the academics collaborated in preparing the mid-semester tests and the final examination. They also all contribute to the materials used in the course, like slides and tutorial worksheets. Likewise, they held team meetings to discuss matters about the course. These activities seem to demonstrate that the academics teaching the course has a good grasp of pedagogical knowledge.

Theme 6: Australian BCMB academics adapt the curriculum to suit students' knowledge, needs, and attitude towards learning

With increased years of experience teaching in the university, it is apparent that academics become highly aware of students' knowledge and needs as well as how they learn. With this knowledge in hand, Australian BCMB academics seem to employ teaching and assessment methods that for them are appropriate to the cohort of students. In some cases, the first thing that they do at the start of the semester is assess the prior knowledge of students on the fundamental concepts in biochemistry. For example, Anna said "*we've got a diagnostic test for the students to do prior to coming in."* The rationale of this diagnostic test is to *"see potentially where students didn't do too well and then we can address that in our lectures and stuff as well."* By conducting a diagnostic test, it appears that Anna has an adequate degree of pedagogical content knowledge by considering the level of knowledge of her students and adjusting the curriculum based on the needs and abilities of her students. Anna's classroom also seems to encourage and promote the constructs of a supportive classroom environment by adapting the curriculum to suit students' academic background.

The same practice was observed with the academics who participated in the classroom observations. The first tutorial session in the semester was devoted to a diagnostic test, while the second tutorial was devoted to discussing the prerequisite concepts in which the students

are weak based on the results of the diagnostic test. These practices seem to show that the academics handling the course have an adequate degree of pedagogical content knowledge by adjusting the curriculum based on the needs and ability of their students. Moreover, these practices appears to show that these academics advocate a supportive classroom environment by adapting the curriculum to fit the academic background of students.

In terms of student's needs, Desiree is aware that some students would like to read prior to attending her class, so what she did is she "*always provide all of the slides upfront … they do have all of the slides in advance."* She also commented that, "*I might also provide some other resource materials upfront maybe some movies or a paper that goes with the work."* Because Desiree is also aware about the attitude of students towards learning, she said "*I don't usually require the students to read something in advance. Sometimes I do but not usually."* In contrast, when Anna was asked how much work she expects her students to do outside class, she said "*I would expect [that]… a student would spend another hour studying."* However, she is also aware that *"realistically they don't, and they wait until closer to the exam and then they study everything."* In the case of Desiree and Anna, it seems that they are both aware about the learning profile and attitude of their students towards learning. Hence, they adjusted their pedagogical decision based on the profile and needs of the cohort of students. These pedagogical decisions appear to show that Anna and Desiree have an adequate level pedagogical knowledge as they adapted the curriculum to suit the academic background of the students.

In the assessments, a few academics also make sure that students are getting what is relevant to their specialisation. For example, Desiree says "*we often give them a choice, so we will build two assessment items that address the same material, roughly the same level of difficulty, …[then] we will make one of them more medically-orientated and the other one more abstract, because a lot of our students are health students and they really want to do the medical one."* Clearly, Desiree is contextualising her assessments based on the interest of her students. This practice shows that Desiree has a good grasp of pedagogical content knowledge by promoting differentiated instruction in her classrooms. It also shows that she is encouraging student direction of activities (supportive classroom environment) by letting student choose a material that is more relevant to them.

Some academics are also aware that a few students in their class have learning disabilities. For example, Leah refers to their online system to check if she has students with a learning disability: "*It may not tell us what their disability is, but it tells us what they need."* Kenneth added that for students with disabilities *"[we] provide extra teaching where needed."*

By identifying the students with special needs, it appears that Leah and Kenneth are employing an inclusive curriculum to engage all students. An inclusive curriculum promotes the elements of valuing and working with difference. It also shows that Leah and Kenneth have pedagogical knowledge on inclusion and differentiation in the curriculum.

However, not all academics adjust the curriculum to suit the students' backgrounds. It seems that some of them do not employ differentiation in teaching. A few academics demonstrated that they do not differentiate the content, the level of delivery or the difficulty of the assessment based on the needs and ability of students (i.e. 'teaching to the middle'). For example, Archie "*used to teach dentistry students in the same class as medical students, and there was a definite bimodal distribution, the dental students were on the bottom in the med class and in the jointly taught science class the agriculture students were very obviously humped at the bottom in that class.*" Hence, his decision is to *"teach to the middle, if you teach to the top of the class you alienate the other 80%, if you teach to the bottom of the class it's so insipidly insulting to the people who've got intelligence, you teach to the middle of the class in that case, trying to be as supportive as possible but not teaching down.*" Francis has the same sentiment in terms of planning the curriculum "*…at this stage I don't try and accommodate the difference, just very minimally*." Because Archie and Francis are teaching a service science course (e.g. Biochemistry and Molecular Biology), which most science students take as a prerequisite to other subjects, it seems likely that they do not see the need to differentiate their teaching. These pedagogical decisions of Archie and Francis seem to show that their pedagogical knowledge on differentiated instruction is limited because it appears that they do not value the elements of valuing and working with difference.

Discussion

Collaboration is the key to innovation

Australian BCMB academics in this study demonstrated pedagogical content knowledge by collaborating to decide on various curricular matters such as course prerequisites, course content, and method of delivery to promote some of the dimensions of productive pedagogy. A review of the extant literature on teacher collaboration suggests that collaboration is a major factor in curricular reforms because teachers learn from each other to improve their own teaching practices (e.g. Brownell, Adams, Sindelar, Waldron, & Vanhover, 2006; Espinosa, Datukan, Butron, & Tameta, 2018; Lucenario, Yangco, Punzalan, & Espinosa, 2016; Shriki & Movshovitz-Hadar, 2011). Hence, even though it is already a common practice in most Australian universities to team teach and collaborate with other academics, it is still a

good practice to retain because, as Brownell et al. (2006) argued, collaboration in itself is a form of professional development for teachers.

However, for a few groups of academics in this study, collaboration becomes negotiation for two reasons: (1) when the course coordinator presents a seemingly viable method in delivering the content, and (2) when a more senior academic, with extensive experience coordinating and teaching a course, suggests a tried-and-tested method in assessing students. It seems likely that the lack of pedagogical training or limited pedagogical knowledge and exposure to education literature could be a reason why some academics in this study willingly agreed to the suggestions of the course coordinator and a more senior academic.

Inclusivity and differentiation promote fair and equitable education for all students

Despite identifying themselves as traditional teachers, majority of BCMB academics in this study demonstrated pedagogical knowledge by adapting the curriculum to suit the students' backgrounds. For example, some academics take the time to check whether there are students in the class needing special consideration, so they can provide modified teaching activities for them - a practice showing that these academics support the constructs of both valuing and working with difference and supportive classroom environment. A large body of literature suggests that inclusion in educational institutions promotes better outcomes not only for students with special needs but also for regular students (e.g. Barry, 1995; Forlin, 2004; Wang, Reynolds, & Walberg, 1995). Although they do not have a framework for inclusion in their classrooms yet, this practice is a good start within the BCMB academic community.

Some academics in this study also expressed that they tailor their teaching and assessment strategies based on students' backgrounds. They employ differentiated instruction to "recognize students varying background knowledge, readiness… preferences in learning, [and] interests" (Hatfield, n.d.). It seems that in this study, academics conduct a diagnostic test primarily to have a glimpse of what students know and what they still need to know to be able to understand more advanced biochemical concepts. Research shows that determining the ability of students prior to entry to university (or in this case, before the first lecture is given) is important in designing the curriculum (Bovill et al., 2011). Moreover, through years of experience in teaching, it also seems that some academics have already become familiar with the attitudes and approaches of students towards learning, as well as their background knowledge; thus, they already know what to expect and how to respond to their needs. Research shows that teaching effectiveness is linked to teaching experience (e.g. Shannon, Twale, & Moore, 1998). It seems that through years of teaching the same courses, academics in this study

have gained pedagogical knowledge and pedagogical content knowledge as demonstrated by them adjusting and adapting the curriculum to suit the background of their students. It was also evident when they integrated some of the elements of productive pedagogy into the methods on how the courses will be delivered.

However, not all academics adapt the curriculum to suit students' backgrounds. As discussed in the previous section of this chapter, they may be resistant to change because of their belief that their discipline can only be taught and assessed in a particular way (e.g. Becher, 1981; Warren Piper, Nulty, & O'Grady, 1996); thus, their decision to 'teach to the middle.' A manifestation that these academics might be lacking pedagogical knowledge to adjust the curriculum in order for it to fit to the background of the students.

Conclusions and Recommendations

In spite of having limited pedagogical knowledge due to limited teaching training and exposure to the education literature, Australian BCMB academics tailor the curriculum to suit the students' backgrounds. It is also apparent that the primary driving force influencing or informing their decision in designing the curriculum is their teaching experience, as well as collaboration and working with other academics to achieve a common goal.

Even though Australian BCMB academics already have experience designing a curriculum, they would still benefit from attending quality professional development for teachers, so that they can plan the curriculum in response to the changing nature of students and expansion of higher education. Moreover, having a good grasp of the theoretical underpinnings of curriculum development will assist them to successfully integrate teaching strategies (e.g. active learning) that will promote independent learning, critical thinking, and self-regulation skills. Acquiring more pedagogical knowledge will also assist them in utilising both the PP and TPACK frameworks into their practice in designing the curriculum.

Chapter 4

Exploring misconceptions as a trigger for enhancing student's conceptual understanding

One way to promote better learning outcomes for STEM students is an improved pedagogical and curriculum design practices of academics. Misconceptions, however, are a potential impediment to achieving this goal because they are commonly believed to have a universally negative impact on the acquisition of new concepts in science. In this chapter, I explored how misconceptions can be utilised to enhance conceptual understanding of students in STEM. From the notion that cognitive disequilibrium, if properly induced, can lead to conceptual change, I exposed second year science students to a misconception-driven tutorial that potentially induces cognitive disequilibrium. Subsequently, I identified possible precursors for conceptual change through qualitative interviews. Using inductive thematic analysis, I identified three themes as precursors for conceptual change: (1) regardless the quality of prior knowledge, students with higher amount of prior knowledge are more likely to have higher confidence, compared to students with lower amount of prior knowledge, (2) students with higher confidence are less likely to change their mind, compared to students with low confidence, and (3) errors made with high confidence are more deeply considered by the students, compared to errors made with low confidence. These findings suggest that to ultimately achieve conceptual change, students need to develop self-regulation, which will enable them to reflect on their own understanding and become sufficiently metaconceptually aware to recognise a cognitive disequilibrium. Being epistemically modest when trying to learn something could also help students understand the concepts better. Additionally, this study revealed that peer collaboration and discourse might not be effective in promoting conceptual change, unless students are self-regulated.

Keywords: cognitive disequilibrium, conceptual change, conceptual understanding, confidence, misconceptions, prior knowledge, self-regulation

Introduction

Infusing active learning is a manifestation of improved pedagogical and curriculum design practices of academics, which has been shown to improve learning gains of students in STEM (Freeman et al., 2014). Scientific concepts, however, are often difficult, complex, and sometimes counterintuitive (e.g. Alvermann & Hynd, 1995; Chi, 2008; Johnstone, 1991).

Hence, science teachers face a challenge in guiding their students to avoid acquiring or reinforcing any of several different kinds of misconceptions while implementing active learning into their classes. For example, factual misconceptions are derived from distorted information presented in different institutions such as schools and media (Hughes et al., 2013). Ontological misconceptions, on the other hand, are rooted from a person's understanding of things (Hughes et al., 2013). The problem with misconceptions is that they impede student progress via two main mechanisms. First, students firmly believe these misconceptions, which makes them hard to rectify through traditional teaching methods (Hughes et al., 2013). Second, these misconceptions affect the students' acquisition of new ideas such that they cannot fully grasp information that is not attuned with their already held misconceptions (Kuhle et al., 2009); thus blocking their ability to learn (Chinn & Malhotra, 2002; Hughes et al., 2013). Despite the best efforts of teachers, some students leave undergraduate courses with uncorrected misconceptions (Finn & Achilles, 1999; e.g. Nehm & Reilly, 2007) and this can therefore pose an ongoing problem for student progress.

A review of the literature suggests that misconceptions in science, technology, engineering, and mathematics (STEM) potentially develop when students are not given opportunities to construct their own understanding of a particular concept (Nakhleh, 1992). This is compounded by students having an informal and instinctive way of understanding things that deviates from the scientific truth, for example from analogies being presented to students in textbooks, and the persistence of many misunderstandings even though a focused instruction had been administered (Anderson, 2007; Badenhorst, Mamede, Hartman, & Schmidt, 2015; Bowling, Huether, Wang et al., 2008; Hanif, Sneddon, Al-Ahmadi, & Reid, 2009; Nakhleh, 1992; Orgill & Bodner, 2006; Reid, 2008; Stern, 2004). Coley and Tanner (2012) explained that misconceptions can originate as 'cognitive construal,' which is considered an unofficial and instinctive perception about a particular phenomenon in a form of an assumption, explanation or a predisposition. For example, there are three kinds of cognitive construals that could be relevant to the development of misconceptions in the biological sciences (Coley & Tanner, 2012): teleological thinking or the "reasoning based on assumption of a goal, purpose or function" (p. 210), essentialist thinking or the "assumption that a core property or feature of a biological structure, species, or system determines its overt features and identity" (p. 211), and anthropocentric thinking or the "tendency to reason about unfamiliar biological species or processes by analogy to humans" (p. 212).

Conceptual change theory has become one of the prevailing theoretical approaches to transforming misconceptions into conventional scientific understanding by reorganising or

modifying the ideas underlying the misconception (Amsel, Baird, & Ashley, 2011; Clement, 1993). Conceptual change theories also reiterate that when incorrect beliefs oppose a newly learned fact, the learning process is compromised (Vosniadou, 2009). In addition, the stronger the hold of the learners to their incorrect beliefs, the harder it is for them to update their conceptual understanding (Dole, 2000). Chi (2000, 2008) advocates for several approaches to achieving conceptual change for different types of misconceptions made on the basis of variations in prior knowledge. Dole and Sinatra (1998) define prior knowledge as "an individual's existing conception regarding an idea, topic, event, or phenomenon" (p. 118). At the propositional or false belief level, in which prior knowledge is either missing or incomplete, direct rebuttal of misconceptions by means of pragmatic substantiation could lead to belief revision (Gadgil, Nokes-Malach, & Chi, 2012). Refutational approaches and ConcepTest (Table 4.1) are some of the best strategies for this type of misconception (e.g. Chew, 2004; Guzzetti, 2000; Kowalski & Taylor, 2004; Kowalski & Taylor, 2009).

Table 4.1

Refutational Strategies for Conceptual Change

Strategy	Description
Refutational text	Refutational texts noticeably show the discrepancy between students' inaccurate ideas and the facts as understood by the field, which consequently leads to easier acceptance of the new information by the students (Guzzetti, 2000). Kowalski and Taylor (2009) suggest that refutational texts should be used in combination with refutational lectures in order to successfully refute misconceptions.
Refutational lecture	This type of instruction starts by activating misconceptions and then the lecturer refutes them by presenting the correct concepts (Kowalski & Taylor, 2004; Kowalski & Taylor, 2009).
Refutational poster	Poster presentations that contain misconceptions and their corresponding rebuttals are said to be a good technique in correcting misconceptions held by the students who prepared and presented the poster and students in the classroom who are the receiver of the presentations alike (LaCaille, 2015).
ConcepTest	The ConcepTest approach administers an assessment through multiple-choice question in reference to common misconceptions (Chew, 2004). As questions are raised, students are asked to respond publicly by raising their hands with the number of fingers demonstrating their answer. Students are next asked to discuss their answers and then asked again to impart what they think is the correct answer. The instructor gives the answer and the appropriate reasoning behind it.

For a misconception related to a faulty mental model, in which the prior knowledge is both missing and incomplete, the 'flawed mental model' or model that is in conflict with what is scientifically accepted could be confronted using holistic strategies and/or multiple refutations to encourage mental model transformation from the accumulation of belief revisions (Chi, 2008). Holistic strategies include having students examine correct and incorrect visual representations and illustrations that will eventually let them revise their own understanding, while multiple refutations include an instruction that requires students to read a piece of writing that describes the correct model (Chi, 2008). These strategies eventually lead the students to assimilate new information into an existing flawed model (Chi, 2008). For categorical or ontological misconceptions, in which the prior knowledge is in conflict with the incoming information, 'robust misconceptions' such as coherently flawed mental models or incorrect models that students consistently use to predict or answer a question, can be confronted by two instructional steps (e.g. Chi, 2008; Vosniadou & Brewer, 1992). The first step is to make the students aware that they have committed a category mistake. The second step is to point out to the student to which category the concept belongs. A detailed description of these approaches on achieving conceptual change for different levels of misconceptions is found in Chi (2008).

Conceptual change process poses a real challenge to science educators and researchers alike because of the cumulative nature of scientific ideas, such that foundational conceptual understanding is required before the more complex concepts can be understood (Zeigler, 2012). Thus, conceptual change in science knowledge is viewed as a gradual and evolutionary process, in which knowledge accumulates until such time that an incongruent idea is discovered and replaced by a more coherent one (Dole & Sinatra, 1998). There are four different views on how conceptual change in science knowledge occurs (see Mayer, 2002): synthetic meaning by Vosniadou (2002), misconception repair by Chi and Roscoe (2002), knowledge-in-pieces by Di Sessa (2002), and sociocultural perspective by Ivarsson, Schoultz, and Säljö (2002). In Vosniadou's (2002) view, conceptual change gradually occurs as students assimilate new information with their existing understanding. Chi and Roscoe (2002) further argue that conceptual change occurs incrementally as students accommodate small pieces of correct mental models to their flawed or incomplete mental model resulting in a completely new mental model. Di Sessa (2002) also agreed that conceptual change is not as simple as replacing intuitive knowledge, called p-prims or phenomenological primitives, into conventional scientific information, but rather it is a multifaceted process of reorganising and integrating knowledge. Ivarsson et al. (2002), on the other hand, believed that conceptual change occurs through social constructivism with the aid of tools particularly made for a certain purpose.

In recent years, science educators have been applying classical approaches (see Posner et al., 1982) in their attempts to achieve conceptual change. In this approach, the lecturers tailor the teaching strategy based on the identified misconceptions of students (Duit & Treagust, 2003). Research shows that teaching strategies anchored on these classical approaches show considerable efficiency compared with more traditional methods of teaching (Duit & Treagust, 2003; Duit et al., 2013). The success of these approaches can be attributed to the potential generation of cognitive disequilibrium between the learners' earlier established beliefs and the correct information that is newly acquired.

Thus, this study explores the opportunity to utilise misconceptions to generate cognitive disequilibrium, which causes students to re-examine concepts that they thought they understood in order to enhance their conceptual understanding. In the research literature, researchers use several different terms (e.g. cognitive dissonance, cognitive conflict) that have similar meanings to cognitive disequilibrium (see Lee & Kwon, 2001). In this study, I will refer to cognitive disequilibrium as a state when "individuals are confronted with stimuli, problems, or situations that present obstacles to goals, anomalous events, contradictions, discrepancies, expectation violations, and obvious gaps in knowledge" (Graesser et al., 2005, p. 1236). The concept of cognitive disequilibrium stemmed from one of the facets of Piaget's (1952) theory on constructivism that states that exposing students to conflicting ideas will enhance understanding of concepts (Baviskar, Hartle, & Whitney, 2009; Gadgil et al., 2012; Kowalski & Taylor, 2009). Studies further show that properly inducing a state of cognitive disequilibrium potentially enhances the acquisition of new information, and specifically in refuting misconceptions (D'Mello, Lehman, Pekrun, & Graesser, 2014; Lodge, Kennedy, Lockyer, Arguel, & Pachman, 2018).

Another factor that I consider in this study is the role of confidence in prior knowledge in the process of conceptual change, as only few studies had been done in this particular area (Cordova, Sinatra, Jones, Taasoobshirazi, & Lombardi, 2014). Confidence is generally believed to be an important factor for a person to succeed both at work and in socialising with others (Bénabou & Tirole, 2002). More specifically, Cordova et al. (2014) defined confidence in prior knowledge as "a retrospective judgment of whether one's current understanding of the topic is correct" (p.165). Cordova et al. (2014) have described the role of confidence in prior knowledge in the process of conceptual change as complex because there are opposing views on its impact. Dole and Sinatra (1998), Linnenbrink and Pintrich (2003), and Pintrich et al. (1993) argue that high confidence or overconfidence in prior knowledge could have a negative influence on the eagerness of a student to learn incoming information, most especially when it

contradicts their existing schema. Lodge and Kennedy (2015) even hypothesised that being less confident when trying to learn something might be more productive than being overconfident. This idea aligns with the concept of epistemic modesty, wherein a person "underestimates self-worth to some limited extent but relative to the available evidence" (Driver, 1999, p. 830). In contrast, Cordova et al. (2014) argued that high confidence in prior knowledge could be beneficial to the process of conceptual change when the error or misconception is pointed out to the student using a focused instruction or intervention. This argument also supports the work of Butterfield and Metcalfe (2006) on the 'hypercorrection effect,' wherein errors or misconceptions made with high confidence are corrected with more persistence; hence the corrections stick more. It is suggested that errors or misconceptions made with high confidence are easier to correct because they catch the attention of students; hence, students pay attention to why they are incorrect (Butterfield & Metcalfe, 2001, 2006; Fazio & Marsh, 2009). However, Butler, Fazio, and Marsh (2011) have contended that errors made with high confidence have the likelihood to reoccur because students have a tendency to forget the correct concept after some time. Furthermore, Sitzman, Rhodes, and Tauber (2014) reiterated that prior knowledge is the primary key to correcting errors, whereas confidence only plays a minor role.

In this chapter, I have identified the potential precursors for conceptual change by exposing students to one of two types of misconception-driven tutorials in an undergraduate biochemistry and molecular biology course. These tutorials were designed to induce cognitive disequilibrium when the students try to employ a strategy for understanding the incoming information that is not effective or not attuned with their prior knowledge. In particular, this analysis probed how students' prior knowledge predicts their degree of confidence and consequently, how this degree of confidence predicts learning. I also discuss the impediments to ultimately achieving conceptual change and how the findings could inform future instruction in STEM.

Methods

Data were gathered through structured face-to-face interviews during the first and second semesters of 2016 in a university in Melbourne, Australia after the students were exposed to one of the two misconception-driven tutorials. (1) The first was a biochemistry tutorial, in which the lecturer administered a concept test (POGIL Biochem Diagnostic Assessment Instrument by Villafañe, Bailey, Loertscher, Minderhout, & Lewis, 2011) to assess students' prerequisite knowledge of essential chemistry concepts crucial to the understanding

of biochemistry and how confident they were in each answer. The lecturer discussed selected concepts that the students got wrong but in which they had a high level of confidence (see Appendix 3). The second was a molecular biology tutorial, in which the lecturer started by showing a multiple-choice question about the structure of DNA that the students needed to answer through online polling. Without revealing the correct answer, the lecturer showed a full structure of a double-stranded DNA as additional information, and then re-asked the same question (see Appendix 4, questions 2 and 3). A detailed description of these case studies is found in Verkade, Lodge, et al. (2017) and Verkade, Mulhern, Lodge et al. (2017).

A total of 28 second year science students were recruited to participate in the interviews by compensating them with a $20 retail voucher. I presented questions about the thought processes that led students to their initial answer, their level of confidence in their answer, whether or not they discussed their answers with their peers, and why they did or did not change their minds after discussing their answers with their peers. Specifically, I asked the following questions:

1. Did you attend the tutorial or watch the recording? What made you decide to do this?
2. What answer did you choose? What thought processes led you to that answer?
3. How confident are you about your answer? Why?
4. Did you discuss your answer with others? If yes, why? If no, why not?
5. Did you change your mind? If yes, why? If no, why not?
6. Why did you change your mind? If yes, why? If no, why not?
7. Can you pinpoint the exact moment in the tutorial when you changed your mind?
8. What do you think triggered the change?
9. How did you feel at that moment?

All interviews were audio recorded and transcribed by myself. Inductive thematic analysis of the interview transcripts was blindly conducted by myself and an experienced inter-rater (a PhD candidate in education) to identify codes and themes. This was followed by a discussion to identify common emerging themes. Inductive thematic analysis refers to "a process of coding the data without trying to fit it into a pre-existing coding frame, or the researcher's analytic preconceptions" (Braun & Clarke, 2006, p. 83). The inductive thematic analysis approach is based on Boyatzis (1998) and Braun and Clarke (2006).

In this study, the first step undertaken in an inductive thematic analysis was a thorough reading of interview transcripts until such time that patterns and connections among the

precursors for conceptual change were identified. The second step was generating codes on precursors for conceptual change from reading and rereading the interview transcripts. The third step was classifying, categorising, and cross-referencing generated codes with the interview transcripts. The fourth step was identifying inductive themes based on the codes generated. Finally, these inductive themes were later on categorised and merged based on major emerging categories. Table 4.2 shows how interview transcripts were coded and how inductive themes were generated.

Table 4.2

Sample coding of interview transcripts and generation of inductive themes

Interview transcript	Code	Category/Theme
"Not too confident… I think I did [change my mind] when xxx clarified… that cap is an activator, so it has the opposite function of the lac repressor" (P17)	Confidence and changing of mind	Degree of confidence predicts decision to change mind
	Memory and peer discussion	Peer discussion triggers memory
"I was very confident because I thought I remembered the content from chemistry last year" (P1)	Confidence and prior knowledge	Prior knowledge predicts degree of confidence

Coding and development of themes was guided by the on-going exploration in the literature of how combining different characteristics of a learner (e.g. prior knowledge and confidence) impact conceptual change. This exploration stemmed from Dole and Sinatra's (1998) Cognitive Reconstruction of Knowledge Model (CRKM) that states that "interactions between message and learner characteristics determine the level of engagement with the topic" (Cordova et al., 2014, p. 165). Guided by this model, three themes about the precursors for conceptual change emerged from the discussion and data analysis of the experiences of the students about the tutorials: (1) students' prior knowledge appeared to predict their degree of confidence; (2) students' degree of confidence appeared to predict their decision to change their mind after discussing with their peers; and (3) students' degree of confidence appeared to predict learning.

Findings and Discussion

Here I will present a critical analysis of the proposed precursors for conceptual change by attempting to establish the impact of prior knowledge and confidence in prior knowledge to changing a student's mind or conceptual change learning. Grounded in Dole and Sinatra's

(1998) CRKM framework, I recognise that every student has existing conceptions or prior knowledge about a topic, and this prior knowledge influences the student's level of metacognitive engagement in receiving new information. Considering all these assumptions, I discuss the potential precursors for conceptual change using the CRKM framework.

Theme 1: Participants' prior knowledge appeared to predict their degree of confidence

Prior knowledge can positively or negatively influence the acquisition of new concepts in science (Pazzani, 1991) because it indicates the students' accurate scientific conceptions as well as their misconceptions (Hewson & Hewson, 1983). In this study, participants clearly made use of their prior knowledge, either from their first-year science courses or high school science subjects, to answer the tutorial questions, as illustrated by the following excepts:

"*I was mainly just trying to remember from last year [first year chemistry], when we learned about pKa and ions.*" (P5)

"*I thought, yeah, cause in high school we learned that hydrogen bonding was anything that's joined by hydrogen bonded to nitrogen, oxygen.*" (P9)

It is also apparent that the varying degrees, whether strong or weak, in which the participants believe in their prior knowledge predicted their degree of confidence. A review of the literature suggests that a major factor that influences students' evaluation of their own knowledge is the level of ease at which the information was obtained (e.g. Benjamin, Bjork, & Schwartz, 1998; Diemand-Yauman, Oppenheimer, & Vaughan, 2011; Kornell, Rhodes, Castel, & Tauber, 2011; Oppenheimer, 2008; Rawson & Dunlosky, 2002; Schwartz, 1994). This self-evaluation eventually predicts the students' degree of confidence. In this study, participants who were confident believed that the concepts were taught in either high school or in first year university science courses, or both, for instance:

"*I was very confident because I thought I remembered the content from [university] chemistry last year.*" (P1)

"*I'd say I was confident because that's what I learned in high school.*" (P9)

It appeared that, in this study, the lectures in high school or in first year university science courses of some participants were given clearly; hence, they are confident in their prior knowledge. Carpenter, Wilford, Kornell, and Mullaney (2013) determined from an experimental study that students have the tendency to be overconfident about their knowledge when a lecture is given clearly. Students assume that they learn more and remember the content better in a well organised lecture compared to a poorly delivered one (Carpenter et al., 2013);

student performance, however, was no different for each groups. Furthermore, studies show that lectures delivered with the use of visual representations would likely influence students to overestimate what they understood from the lecture (e.g. Carpenter & Olson, 2012; Serra & Dunlosky, 2010). Teaching the STEM disciplines is always accompanied by images, figures, illustrations, and increasingly, adaptive multimedia simulations etc., making some students feel confident that they fully understood the content and decide to stop studying (Carpenter et al., 2013).

On the contrary, participants who were not confident believed that the concepts were not taught in either high school or in first year university science courses; hence, they resorted to guessing. The following examples show that prior knowledge has an impact on the confidence of participants:

"*I was really uncertain, I'll give it like 50% [confidence]… I don't think I really learned hydrogen bonding… in high school.*" (P4)

"*I was not very confident because I couldn't remember this topic, so I just gave a random guess.*" (P25)

"*Not really confident… I just guessed because I didn't know what the thought process was to get the answer.*" (P20)

Cordova et al. (2014) discovered from their experimental study that students with low confidence in their prior knowledge exhibited a significant decrease between their immediate post-test scores and their delayed post-test scores; thus, retention of concepts is low for students with low confidence in their prior knowledge. This group of students from the same study were significantly more likely to have a misconception compared to students with high confidence (Cordova et al., 2014). In this study, it also seems likely that these students with low confidence in their prior knowledge would commit errors or misconceptions based from their reasoning on how they decided to choose their answers.

Theme 2: Participants' degree of confidence appeared to predict their decision to change their mind after discussing their answers with their peers

Peer collaboration and discourse is one way of exposing students to the conflicting ideas of their peers (Howe, Tolmie, & Rodgers, 1992). This peer collaboration can either confirm or contradict students' understanding of concepts. A contradictory understanding of concepts triggers cognitive disequilibrium because the students are unable to bridge the gap between their prior knowledge and incoming information (D'Mello et al., 2014). Cognitive disequilibrium is unlikely to be avoided in complex learning tasks like peer discussion

(D'Mello et al., 2014), and if not sufficiently addressed, could bring about frustration and/or boredom in students (D'Mello et al., 2014). Hence, lecturers need to provide meaningful scaffolding with prompt and constructive feedback to the students (Lodge & Kennedy, 2015). In the tutorials in this study, the lecturers encouraged the participants to first answer the tutorial questions on their own. Afterwards, the lecturers let them share and discuss their answers with their peers; cognitive disequilibrium is potentially induced in this part of the learning process. Findings of this study show that confidence influenced the participants' decision to reassess their understanding of concepts, prompting them to either change or not change their minds after the process. Participants with a high level of confidence did not easily change their mind after the peer discourse, for instance:

"*I was probably 7 or something out of 10 [confident]… I don't think [I changed my mind].*" (P5)

"*I was 60-70% sure about that. [Discussing with my peer] didn't really help that much… purely because the student himself wasn't confident.*" (P10)

It seemed that a peer's level of confidence could also influence participants to either change or not change their minds. Similarly, participants who think that they are academically better than their peers also did not change their mind, for example:

"*Oh, I was pretty sure. I finished it straightforward… No, [I did not change my mind], probably like, we're honour students and top students.*" (P13)

It also seemed that the participants' level of confidence stemmed from their own perception about themselves. A review of the extant literature suggest that it is common for students to overestimate what they know (e.g. Castel, McCabe, & Roediger, 2007; Dunlosky & Rawson, 2012; Kornell & Bjork, 2009). However, overestimation of understanding could prompt the students to stop studying the content before they fully understand it (Carpenter et al., 2013). This overestimation of knowledge could explain why some participants with high levels of confidence did not perform well in some of the questions in the tutorials when they were asked to reconsider the question after the peer discussion.

On the other hand, students with low levels of confidence were easily influenced by their peers to change their mind, as illustrated by the following examples:

"*I was not confident at all… Yes, [I changed my mind] because mine was wrong.*" (P3)

"[My confidence] was around 3 or 4 out of 10, where 10 is most confident… Yes, [I changed my mind because] my friend, when he explained his answer, he talked about how the alpha helix was too small in interior to have any waters within, and that made sense to me." (P23)

"*Not quite [confident]. Yes, [I changed my mind] because their answers… [make] more sense to me and [they] explained it better.*" (P8)

It appeared that these participants changed their minds possibly because their peers were more confident with their answers. The problem with some students who appeared to be confident is that they might just be using unproductive argumentation techniques to defend their answers (e.g. Chan, 2001); hence, students with low confidence and low metaconceptual awareness could easily be swayed to change their mind. Another possible reason for students with low levels of confidence to be easily influenced by their peers to change their mind could be due to epistemic modesty. Students with low confidence could just be epistemically modest, wherein they have the tendency to undervalue their ability to accomplish something (Driver, 1999).

There were also students who were confident about their answers but decided to change their minds after the peer discussion, for instance:

"*I was very confident. Yes, [I changed my mind]. The realisation of the correct answer, I suppose [triggered the change] and my memory of having wrote [sic] that previously but forgetting it, and then being re-taught it I suppose from the other person.*" (P1)

"*I'm confident... Yes, [I changed my mind]. I sort of remember all the stuff.*" (P7)

It seems that in these cases, peer collaboration and discourse triggered the memory of some of the students, allowing them to reconsider their own understanding. This finding supports Metcalfe and Finn (2011) "knew-it-all-along" argument for errors made with high confidence. The students just need immediate feedback, either from the lecturer or a classmate, to trigger the memory of a concept.

Theme 3: Participants' degree of confidence appeared to predict learning

In learning new information, students should recognise what information they already know, and what they still need to know. When they are unable to find a connection between what they know and new information that is introduced, they will most likely end up in a state of cognitive disequilibrium (D'Mello et al., 2014). Cordova et al. (2014) argued that if cognitive disequilibrium was not recognised, students who are overconfident would try to connect the new information with their prior knowledge, whether it be accurate or inaccurate. In this study, I probed into the effects of overconfidence in prior knowledge to learning. Findings show that participants who have high confidence with their answers remembered the concepts better when they got it incorrect. The following excerpts illustrated this example:

"*I'm confident… I discussed it a bit [with my classmate]. Sort of it reached the conclusion and then it was the right answer eventually… I was sort of happy because I got to figure it out now.*" (P7)

"*I'd say I was confident… Yes, I discussed it with someone else after, and then that changed my view… It's actually one of the really good things to learn at some point in this subject, so I won't just go on the whole time now knowing that was right when it's not. It means so much in Biochemistry.*" (P9)

"*Oh, I was pretty sure. I finished it straightforward…When [my classmate] said that you have to have the hydrogen form in the bond like in the other atom, it actually has to be electronegative, and I kind of flicked the light bulb on my head because I couldn't figure out any reason why it wouldn't work. And then as soon as we're called in there, I feel like actually, yeah that makes sense… [I] felt kind of stupid but happy that I've learned something.*" (P13)

In this study, it seemed that the participants with a high level of confidence held on to their beliefs, but when they found out that what they believed was incorrect, they reported a feeling of surprise. This finding shows that students with a high level of confidence remember the concepts better because they were conscious about how they take in new information, which is also an indicator that these students have high metaconceptual awareness. For this reason, it is important that cognitive disequilibrium is recognised when it occurs. A review of extant literature shows that conceptual change will only happen when students recognise that a state of cognitive disequilibrium is happening when they reflect on their understanding (e.g. Chan, Burtis, & Bereiter, 1997; Dreyfus, Jungwirth, & Eliovitch, 1990; Hewson & Thorley, 1989; Howe et al., 1992; Tao & Gunstone, 1999). However, other studies have shown situations in which it is difficult for students to resolve the uncertainty brought about by cognitive disequilibrium (e.g. Dreyfus et al., 1990), which can be an indicator that these students have low metaconceptual awareness. Thus, they need meaningful scaffolding with prompt and constructive feedback to resolve the uncertainty (Lodge & Kennedy, 2015).

Participants who were not confident with their answers may not be likely to remember the concepts that they got incorrect. For instance:

"[I was] not too confident… I think both me and my classmate weren't too sure. But once [the lecturer] clarified it, we knew that, okay, cap is an activator, so it has the opposite function of the lac repressor. I sort of understood what she's saying but I still think I need a revise of the topic." (P17)

"*[My confidence] was around 3 or 4 out of 10, where 10 is most confident… For me, even though something makes sense, I don't want to say that's the absolute correct answer.*" (P23)

It seemed that in this study, participants with a low level of confidence lack the ability to critique the new information, because they have low metaconceptual awareness.

Metaconceptual or metacognitive awareness is essential in promoting deeper inquiry (Chan, 2001). For this reason, these students become susceptible to acquiring wrong information through misunderstanding or misinterpretation of a presented concept that potentially leads to misconceptions. Vosniadou and Kollias (2003) further noted that students with low metaconceptual awareness are more likely to hold misconceptions, because they do not consider their own knowledge. Furthermore, these students may or may not fully comprehend the theoretical basis of concepts; therefore, they are not really aware whether what they learned was correct or otherwise. As such, their understanding of the concept may not be valid.

Metaconceptual awareness is closely aligned with students' critical thinking ability and other cognitive skills. Students with strong critical thinking ability are more likely to be resistant to misconceptions (Taylor & Kowalski, 2004). This critical thinking ability also enables individuals to identify possible misconceptions. Hence, it is apparently easier for highly critical thinkers to resolve their misconceptions, as they are more observant to when they occur (Bensley, Lilienfeld, & Powell, 2014; Kowalski & Taylor, 2004). In this study, it seems that the students with high level of confidence may also have high critical thinking skills because they were able to discern discrepancy in their own understanding; hence, my hypothesis is that they remember the concepts better than the students with low level of confidence. However, in this study I have not examined the rebound effect, which can happen when correcting misconceptions, wherein misconceptions that are addressed recur months later when course content has progressed to another topic (Lyddy & Hughes, 2012).

There are also a few participants who were not confident and got the item incorrect, but apparently remembered these concepts well, for example:

"*Not very [confident]. At that time, I was trying to remember what was like which, identify the transcription factors so that was basically what made me feel unsure… I think the whole process [of] going through choosing the wrong answer actually made me remember [the concept] well.*" (P21)

It appears that the level of confidence is not the only factor for some students to remember the concepts. In certain instances when they get the concept wrong and the correct answer was presented, their recollection of that concept was triggered and they understood the topic better. This finding contradicts the "knew-it-along" argument of Metcalfe and Finn (2011). In this case, even if the students have low level of confidence, feedback from their peers seemed to trigger their memory about a concept. However, further studies with more students are needed to make a conclusion. Another possible reason is that this particular student

was just being epistemically modest, wherein they undervalue what they know (Driver, 1999) because they have a low level of confidence in their prior knowledge.

Implications for practice

Cognitive conflict induced during peer collaboration and discourse, has long been known to have an impact on the cognitive development of a person (Piaget, 1959). Chan (2001) observed, in an experimental study participated by Canadian grades 9 to 13 students, that students who engaged in peer collaboration and discourse developed cautiousness in acquiring new information, which eventually helped them identify and detect discrepancy in their own understanding. Thus, in this case, collaborating or working with their peers encouraged an exchange of ideas, allowing the students to reflect on their answers and assess whether they are valid or not. This event also lead to a productive epistemological framing because students was able to generate and assess their ideas whether it makes sense or not. Epistemological framing refers to "how students understand their own activity with respect to knowledge and learning" (Hutchison & Hammer, 2009, p. 508).

However, it seems that only students with high self-regulation skills are able to benefit from peer collaboration and discourse, and students with low self-regulation skills would not potentially benefit. Self-regulated learners are independent thinkers who actively take the initiative to choose, accomplish and evaluate their own learning (Winne & Hadwin, 1998). Thus, it is easier for them to recognise a discrepancy between their own understanding and information presented by a peer. If students are not self-regulated, the event will lead to an unproductive epistemological framing, wherein students only do peer discussion because it was sanctioned by the lecturer. In this case, the enactment of the activity may not translate to generation and assessment of ideas.

A large body of literature also supports the argument that collaborative and cooperative approaches promote better learning outcomes for students (e.g. Ambruster et al., 2009; Armstrong et al., 2007; Eison, 2010; Faust & Paulson, 1998; Michael, 2006; Prince, 2004; Smith, 2000). However, I argue that the problem with most of these studies is that they rely on outcomes (e.g. post-test scores) as a definitive indicator of success, rather than considering what transpired during the peer collaboration and discourse itself, which can be examined by recording and transcribing the discourse. Chan (2001) concluded that peer discourse does not automatically promote conceptual change, Chi (1996) and Graesser and Person (1994) suggested that the discourse transcripts should be deeply examined by the lecturer to see whether deep learning and refutation of misconceptions occurred or not. Examining discourse

transcripts, however, would be impossible for large class settings. I suggest the use of a polling software (e.g. *Poll Everywhere* or *SurveyMonkey*) in the case of large classes, where students can send their refutation to a misconception. The lecturer, then, selects the best refutation and explains why it is the correct answer. This event will potentially trigger students to realise that their argument was wrong and correct it eventually.

Eichinger, Anderson, and David (1991) and Mercer (1995) further argued that peer discourse might not be very productive for two reasons. First, students bring in prior knowledge that could be accurate or inaccurate (Chan, 2001; Hewson & Hewson, 1983; Zeidler, Lederman, & Taylor, 1992). Indeed, in this study, participants were using their prior knowledge from high school or university science courses to answer initial questions, as well as when they were asked to reconsider. Second, students may use unproductive argumentation techniques in order to defend their claims (Chan, 2001) and contradict other students' ideas. Unproductive argumentation techniques refer to rhetoric aimed at persuading someone to believe in their argument. It is also likely that the students who use unproductive argumentation techniques would appear to be highly confident; hence, the tendency is that students with low metaconceptual awareness would easily believe their argument, whether it is correct or not. In this study, the learning event often eventually prompted the students with low metaconceptual awareness to change their minds during the peer discussion.

In an experimental study, Chan (2001) described three possible reasons why peer collaboration and discourse was not effective in their context. First, they did not give specific instructions on how students should collaborate (i.e. whether they work on their own first then discuss it with their peers or not). In this study, the lecturers asked the students to answer the tutorial questions on their own first then discuss them with their peers. Second, the groupings in Chan's (2001) study were in no particular arrangement (i.e. students were not grouped according to certain parameters like initial conceptions or prior knowledge). The lecturers in this study asked students to work in pairs or small groups based on where they were seated. Third, when Chan (2001) exposed students in pairs to external conflict brought about by flawed arguments, it did not eventually lead to conceptual change. This event led her to conclude that simply presenting external conflict to students in a collaborative setting was not enough to promote conceptual change; internal conflict that are meaningful should also be experienced by the students. In this study, I did not examine the discourse between the students in pairs versus larger groupings. Studies show that it is only by looking at the full transcript of a peer discussion where the lecturer would know whether deep learning and refutation of misconceptions occurred or not (e.g. Chi, 1996; Graesser & Person, 1994).

Chan (2001) further conducted comprehensive analyses of discourse transcripts made by the participants from the same experimental study. Results show that peer collaboration and discourse worked better for mature, older students compared to younger ones, potentially because they may have more experience on collaborative learning, which leads to deeper and more meaningful inquiry, as shown by the patterns of their discourse. This observation aligns with Inhelder and Piaget's (1958) hypothesis that acquisition of complex knowledge is hierarchical; it is only during the formal operational stage or adolescence stage that children are capable of thinking scientifically. I would argue further that mature, older students have better capacity to self-regulate compared to younger students. The participants in this study were second year students, most of them ages of 19 and 20, which are slightly older than Canadian grade 13; hence, they may be more capable of self-regulation and would have had more experience with collaborating in a classroom setting.

As an alternative to peer collaboration and discourse, a guided collaborative inquiry (see Martin-Hauser, 2002; Windschitl, 2003) in a classroom setting is suggested. This method requires students to monitor their own learning, as well as the learning of their peers. In a guided inquiry, the lecturer gives specific guidelines on how the task should be done. In addition, the lecturer also gives instructions how students should assess their own understanding, as well as their peers. This method may also work best if the lecturer monitors the proceedings of the peer discussion by asking the students to submit a report. Potentially, doing this activity frequently could eventually lead to development of self-regulation among the students.

Conclusions

The cognitive disequilibrium that the revealing of the misconceptions create can be capitalised on by lecturers to enhance conceptual understanding of students in STEM, if properly induced and resolved. In this chapter, I presented potential precursors for conceptual change that can inform future instructions in STEM. The amount of prior knowledge, regardless the quality, appeared to predict degree of confidence. The degree of confidence in prior knowledge appeared to predict decision to change minds in a collaborative setting. And finally, the degree of confidence in prior knowledge also appeared to predict learning and retention of concepts. I argue that for the learning process to ultimately lead to conceptual change and deep learning, students need to self-regulate to be able to reflect on their own understanding and become more metaconceptually aware so that they recognise any state of cognitive disequilibrium. I also recommend guided collaborative inquiry as an alternative to

peer collaboration and discourse, as it is more structured and validated. For future research on peer collaboration and discourse, it would be good to examine discourse transcripts during the peer discussion, in addition to structured face-to-face interviews, to strengthen the understanding of the precursors for conceptual change.

Chapter 5

Enhancing students' conceptual understanding and engagement through active learning tutorials

Teaching in large class setting increases the likelihood for undergraduate students to go through science classes with uncorrected misconceptions that eventually hamper the learning process. Misconceptions can be resolved through conceptual change – by reorganising or modifying the ideas underlying the misconception. One of the best approaches academics can apply to fostering conceptual change is to infuse active learning into their teaching practice. In particular, active learning approaches that capitalises on the cognitive disequilibrium have been shown to improve the conceptual understanding of students. In this chapter, I explore the effectiveness of an active learning tutorial in comparison with a didactic tutorial in enhancing students' conceptual understanding and engagement. In the active learning tutorial, the students discussed an intentionally flawed manuscript that contained misconceptions, while in the didactic tutorial the lecturer explained how to answer questions given to the students in advance. A standard cross-over design was used in the study, wherein the students carried out one active learning tutorial and one didactic tutorial. Conceptual pre-test and post-test and engagement self-report were then administered to measure the variables being tested. Results show that both tutorials have comparable increases in pre-test and post-test scores and comparable levels of student self-reported engagement. However, independent classroom observers reported that this intervention improved student engagement. The literature on student engagement suggests that engagement is predominantly linked to improved learning outcomes. The comparable increases in conceptual understanding and student self-reported engagement can be attributed to the seemingly equivalent delivery of the didactic and active learning tutorial.

Keywords: cognitive disequilibrium, conceptual change, conceptual understanding, student engagement, active learning

Introduction

One of the critical roles of research on conceptual change is to improve how we teach science, technology, engineering, and mathematics (STEM) in school or university. Conceptual change research examines how to change students' misconceptions into conventional scientific information (Amsel et al., 2011; Clement, 1993) using teaching

strategies that challenge them to use their self-regulation skills. For research on conceptual change to be beneficial, it is imperative that intervention studies be part of the program (Mayer, 2002).

Intervention studies on conceptual change research are usually influenced by different models of conceptual change discussed in Chapter 4, such as synthetic meaning (Vosniadou, 2002), misconception repair (Chi & Roscoe, 2002), and knowledge-in-pieces (Di Sessa, 2002). Alternatively, intervention designs can be influenced by impasse-driven theories of learning (VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003), cognitive disequilibrium theories of learning (Festinger, 1962; Piaget, 1952), and concept of desirable difficulties in the learning process (Bjork & Linn, 2006; Linn, Chang, Chiu, Zhang, & McElhaney, 2011). Most of these intervention studies highlight the importance of creating a learning environment that is active and less traditional.

It has also been suggested that in order for an intervention to be successful, difficulties that induce impasse and cognitive disequilibrium should be integrated into the learning process (Lodge et al., 2018). Graesser's (2011) zone of optimal confusion (ZOC) further suggested that the level of difficulty brought about by confusion should be appropriate for the ability of students – it should not be too easy or too difficult. Otherwise, the confusion will turn into boredom or frustration, which is not helpful for learning. Building from the work of Graesser (2011) on ZOC, Lodge et al. (2018) proposed a framework for confusion using cognitive disequilibrium as a medium for learning (see Figure 1 in Lodge et al., 2018). In this framework, the cognitive disequilibrium is generated through the confusion brought about by an impasse (e.g. a misconception). As long as students find the instructional strategy to be engaging, they will move to the ZOC. Lodge et al. (2018) illustrated this concept using the intervention study of Muller, Sharma, and Reimann (2008). Muller et al. (2008) used video dialogues involving misconceptions to induce cognitive disequilibrium with the students. If the student has adequate metaconceptual awareness to recognise the confusion and to change strategy in solving a problem, the cognitive disequilibrium will be resolved and will eventually lead to conceptual change. However, if the confusion remains unresolved after some time, the student will potentially move to the zone of sub-optimal confusion (ZOSOC) leading to an unproductive learning event (Lodge et al., 2018). Lodge et al. (2018) further noted that for confusion to translate into learning, the student should have adequate skills in self-regulation. Thus, interventions that potentially perplex learners would be best only for students with high self-regulation skills because they "want to be challenged with difficult tasks, are willing to risk failure, and manage negative emotions when they occur because they understand that

failure is an inevitable part of a successful path toward proficiency development" (D'Mello et al., 2014, p. 168). Students with low self-regulation skills would not benefit in such instructional strategy because they lack the required skills and attitude towards learning.

It is worth remembering that interventions sometimes show unimpressive results in trials because they frequently fail to create a meaningful cognitive conflict and usually appear in "one-size-fits-all" model, wherein the intervention is assumed to fit all students regardless of their individual differences and prior knowledge (D'Mello et al., 2014; Limón, 2001). The researchers' only concern is to examine the cognitive processes of the learners (D'Mello et al., 2014). Moreover, in most intervention studies, the effects of interacting with peers in a collaborative setting is only superficially examined (D'Mello et al., 2014), wherein the only definitive measure of success is test scores. Hence, in this study I examined student engagement in peer collaboration both qualitatively and quantitatively to fill the gap in most intervention studies. Details about this will be discussed in the next section.

Social interactions in a collaborative setting have the potential to keep the students engaged. When the students are sufficiently engaged, aside from being adequately confused due to an impasse, they will move to the ZOC (Lodge et al., 2018). Klem and Connell (2004) and Krause (2007) even added that when students are engaged, improved learning outcomes will follow. However, engagement does not simply mean attending classes or performing activities in class, but also self-regulating one's behaviour to achieve a certain goal by doing one's best while at the same time enjoying the challenges of learning (Klem & Connell, 2004; National Research Council and the Institute of Medicine, 2004). Student engagement has three fundamental classifications: affective-emotional engagement, behavioural engagement, and cognitive engagement (Appleton, Christenson, & Furlong, 2008; Fredricks, Blumenfeld, & Paris, 2004; Furlong & Christenson, 2008). Affective-emotional engagement refers to a student's negative or positive disposition towards peers, teachers, and the school itself (Fredricks et al., 2004). Behavioural engagement refers to the conduct or deportment of a student in school (Finn & Zimmer, 2012). Cognitive engagement, on the other hand, refers to "thoughtfulness and willingness to exert the effort necessary to comprehend complex ideas and master difficult skills" (Fredricks et al., 2004, p. 60). Bonwell and Eison (1991) argue that students being cognitively engage with learning activities or materials is the best description of active learning. To categorise learning tasks in an active learning classroom, Chi and Wylie (2014) developed the interactive, constructive, active, and passive (ICAP) framework. On the passive level, students receive information without interaction. On the active level, students manipulate learning materials to deduce the information. On the constructive level, students

create a novel output by synthesizing their own ideas. On the interactive level, students engage in peer discussions to generate new knowledge or ideas.

One of the many activities a lecturer can implement in class to keep students cognitively engaged in the interactive level is the critical reading of scientific papers. However, it is not an easy task. Teaching undergraduate students how to read scientific papers critically could be one of the most challenging tasks for STEM academics (Ferenc, Červenák, Birčák et al., 2018). But, it is an essential skill for scientists (Verkade & Lim, 2016) so it should also be developed by science students. To respond to this challenge, some STEM academics have formulated teaching strategies that integrate reading scientific papers into their classes. A prominent example in biomedical sciences is the CREATE strategy: Consider, Read, Elucidate hypotheses, Analyze and interpret data, Think of the next Experiment (Gottesman, Hoskins, & Vazquez, 2013). Other key examples are Figure Facts (Round, Campbell, & Siegel, 2013), and journal clubs (Esisi, 2007). In the CREATE strategy, students are asked to read papers published by a particular laboratory in chronological order. This strategy trains students to specialise in a particular field by following the way scientists develop ideas and theories (Gottesman et al., 2013). The Figure Facts strategy trains students to focus on the data being presented in the paper, instead of just merely reading the text in the paper (Round et al., 2013). Journal clubs or 'reading groups' is probably the most popular among these strategies across disciplines. In this strategy, the club moderator (which is usually the principal investigator) selects a paper for reading. Then, the club members are asked to summarise the main argument and significance of the paper and critique the content of the paper based on how it was presented (Esisi, 2007). Reading scientific papers critically on a regular basis will not only enrich the knowledge of the students but will also familiarise them with the structure and language used in their discipline, making it easier for them to point out the strengths and flaws of the paper. However, most scientific papers are hard to understand for undergraduate students because of their specialist nature, making detection of errors by students highly improbable (Ferenc et al., 2018). In this example, the lecturers used intentionally flawed manuscripts that are easy to read, to teach undergraduate students how to detect errors in scientific writing. This activity trains the students to read papers critically and encourages peer discussion (Ferenc et al., 2018).

In this study, students were exposed to one of two types of tutorials in an undergraduate biochemistry and molecular biology course: an active learning tutorial and a didactic tutorial. In the misconception-driven, active learning tutorial, the students were given intentionally flawed manuscripts, while in the lecturer-driven, didactic tutorial, the students were delivered

a ‘lectorial,’ whereby the lecturer explained how to answer multiple-choice and free response questions regarding a particular topic. The active learning tutorial was implemented through a guided collaborative inquiry based on IMPROVE (Introducing the new concepts, Metacognitive questioning Practicing, Reviewing and reducing difficulties, Obtaining mastery, Verification, and Enrichment) method (Mevarech & Kramarski, 1997). This method uses self-questioning strategies in solving problems through the following metacognitive strategies: (a) comprehending the problem, (b) bridging ideas between the previous and the new knowledge, (c) applying appropriate strategies to solve the problem, and (d) reflecting on the processes to come up with the solution (Kramarski & Mevarech, 2003). The intentionally flawed manuscripts used in this study were hypothesised to induce cognitive disequilibrium when the students hunt for errors or misconceptions. Hence, the manuscripts were designed to signal to the students to change strategy in order to detect the error. This study examined the effectiveness of the active learning tutorial by comparing with the didactic tutorial: were students more engaged and have higher conceptual understanding in the active learning tutorial or the didactic tutorial?

Methods

Study Design

A standard cross-over design was used in the first half of the study (first semester, 2017). In this design, each student carried out one of the active learning tutorials and one of the didactic tutorials (Table 5.1). The students were assigned to sessions by the timetable generator depending on their availability. To ensure equity, every student had access to all the resources (written materials and the recordings) from both tutorial versions after the last tutorial session of the week, as is usual for this subject. Based from the results of the first semester, the intervention was trialed again in the second semester of 2017. However, there was only one tutorial session scheduled in the second semester. Hence, in the second half of the study, a one-group pretest-posttest design was utilised. In this design, all students carried out the active learning tutorials (Table 5.1). In this second half of the study, I interviewed students to establish which of the tutorials was most engaging, with three participants.

Table 5.1.

Biochemistry and molecular biology tutorial schedule for academic year 2017

		First semester		Second semester
Trial week	Session A	Session B	Session C	Session A
1	Didactic tutorial	Didactic tutorial	Active learning tutorial	Active learning tutorial
2	Active learning tutorial	Active learning tutorial	Didactic tutorial	Active learning tutorial

Participants

The participants were second year science students enrolled in a biochemistry and molecular biology course in a university in Melbourne, Australia. The study was conducted in weeks 10 and 11 of the 12-week teaching semester. The topics covered were membranes and lipids in week 10, and metabolism in week 11. In both semesters trial 1 occurred in week 10 and trial 2 occurred in week 11. Weeks 1-9 resemble that of the didactic tutorial wherein the lecturer went through how to answer questions that the students have possibly attempted at home.

In semester 1, for trial 1 there were 119 students (33 in session A and 86 in session B) in the didactic tutorial and 72 students in the active learning tutorial (session C) who consented for their data to be used in the study. A total of 220 students were in attendance in trial 1. In trial 2, 68 students in the didactic tutorial and 109 students (69 in session A and 40 in session B) in the active learning tutorial participated in the study. A total of 214 students were in attendance in trial 2. In semester 2, 34 students in trial 1 and 60 students in trial 2 consented for their data to be used in the study. A total of 39 students and 67 students were in attendance in trial 1 and trial 2 respectively.

Intervention

Active learning tutorial

In the active learning tutorial, the students were given a lecturer-made intentionally flawed scientific manuscript in class (see Appendix 5 for a sample text). The intentionally flawed manuscripts aim to induce cognitive disequilibrium to the students by using misconceptions as a core teaching strategy. This active learning tutorial was formulated from the notion that cognitive disequilibrium, if properly induced and resolved, can lead to conceptual change. The active learning tutorial was implemented through a guided collaborative inquiry, wherein the lecturer provides the materials and the problems to be investigated while the students find ways to solve the problem (Martin-Hauser, 2002;

Windschitl, 2003). The lecturer provided instructions following Mevarech and Kramarski (1997) IMPROVE method, which had the following steps: (1) The students were asked to read and identify errors individually in an intentionally flawed manuscript. (2) The students were asked to discuss the manuscript in pairs to identify the flaws/misconceptions. (3) The students discussed how to 'refute' the misconception and composed a sentence to refute it. (4) The students were asked about the location of the flaws and then the locations were confirmed by the lecturer. (5) Each pair was asked to post their refutation statement using *Poll Everywhere* software. (6) The lecturer then chose the best three to five responses to present and discuss in the class. Both trials 1 and 2 active learning tutorial were designed by the lecturer who also carried out the experiment.

Didactic tutorial

In the didactic tutorial, the lecturer gave a 'lectorial' explaining how to answer questions that were given in advance to the students. Trial 1 didactic tutorial was designed by a more traditional lecturer. Trial 2 didactic tutorial, on the other hand, was designed by a more innovative lecturer who also carried out the experiment.

Instruments

Conceptual pre-tests and post-tests

To measure the conceptual understanding of the students, the lecturer developed two sets of conceptual pre-test and post-test (see Appendix 6 for the sample questions). The first set covered membranes and lipids, while the second set covered metabolism. Both the pre-tests and post-tests consist of a 5-item multiple-choice questions that were answered on a computer mark sheet.

Engagement vs Disaffection with Learning (EDL): Student self-report

To measure the engagement of the students, a 10-item version of the Likert-scale *Engagement vs Disaffection with Learning (EDL): Student self-report* (Appendix 7) developed by Wellborn (1991) was used in the study. This shortened version was composed of three behavioural engagement statements, three behavioural disaffection statements, two emotional engagement statements, and three emotional disaffection statements. Furrer and Skinner (2003) calculated the Cronbach's alpha (α) of the original instrument and was found to be .89; the behavioural engagement part has α of .75, while the emotional engagement part has α of .86. The calculated α lie within the accepted range of .70 to 1.0 (see Fraenkel & Wallen, 1993). The

validity and reliability of this instrument is further described in Furrer and Skinner (2003) and Wellborn (1991). Students answered this self-report on a computer mark sheet.

Classroom Observation Protocol for Undergraduate STEM (COPUS)

To triangulate the engagement self-report of students, as well as to describe the actions of the lecturer in the classroom, the *Classroom Observation Protocol for Undergraduate STEM (COPUS)* instrument developed by Smith, Jones, Gilbert, Wieman, and Dolan (2013) was utilised. Two experienced, independent classroom observers, who are PhD candidates in higher education, were employed to use the COPUS instrument. Both received a short training session on how to use the instrument. They practiced twice in using the instrument before the actual observation. The independent classroom observers provided a short reflection after every tutorial. The COPUS instrument has Cohen kappa (κ) coefficient ranging from .79 to .87, which are very high scores and therefore suggest a good interrater reliability (Landis & Koch, 1977). The validity and reliability of this instrument is further described in Smith et al. (2013).

Data Collection Procedure and Analysis

The same lecturer carried out the active learning and didactic tutorials in both trials 1 and 2. At the start of the tutorial, the lecturer administered a conceptual pre-test on computer mark sheets for approximately seven minutes. The first question asked whether the students were willing to share their data for the study. The pre-test was followed by the implementation of the intervention (or didactic tutorial), which lasted for about 33 minutes. A 10-minute conceptual post-test and engagement self-report on computer mark sheets were administered afterwards. From the data, I removed any student who selected 'no' to the consent question, and then matched pre-test and post-test data from all the other students. Finally, I removed all identifying information. Students were offered a personalised email with their pre-test and post-test scores, which was independent of their consent to be included in the study. This personalised email was expected to induce motivation amongst students to be involved in the study.

The first semester conceptual pre-test and post-test, as well as the engagement self-report were subjected to descriptive statistics and repeated measures (mixed-design) analysis of variance (ANOVA) with Greenhouse-Geisser correction using *Jeffreys' Amazing Statistics Program* (JASP) software developed by the JASP Team (2018) of the Department of Psychological Methods of the University of Amsterdam. The Greenhouse-Geisser correction is used to correct for sphericity, wherein it alters the degrees of freedom to adjust the

significance value of the *F* ratio thereby controlling for Type I error (Horn, 2008). The second semester conceptual pre-test and post-test were subjected to descriptive statistics and dependent or paired samples *t*-test using SPSS. It should be noted that mixed ANOVA and paired *t*-test only account for the effects of the instructional intervention and not the differences in the characteristics of students. Effect sizes are reported to account how much the intervention worked independent of the sample size.

Data gathered from the COPUS instrument were encoded in Microsoft Excel, and this software was utilised to generate pie charts to compare the overall activities of the students and the lecturer.

Results

Analysis of students' conceptual understanding

Significant differences between the students' conceptual pre-test and post-test scores were observed for all of the tutorials using repeated measures ANOVA with Greenhouse-Geisser correction (Table 5.3), $F(1,178)=28.761$, $p=.001$, $\eta^2=.139$. These results suggest that the scores of students exposed to either the didactic or active learning tutorials increased after the tutorial session (see Figure 5.1 and Table 5.2). A 2.03% difference for the learning gains of students between the didactic (12.47%) and active learning tutorial (14.5%) was noted. These results suggest that the learning gains of students exposed to an active learning tutorial were higher compared with a didactic one.

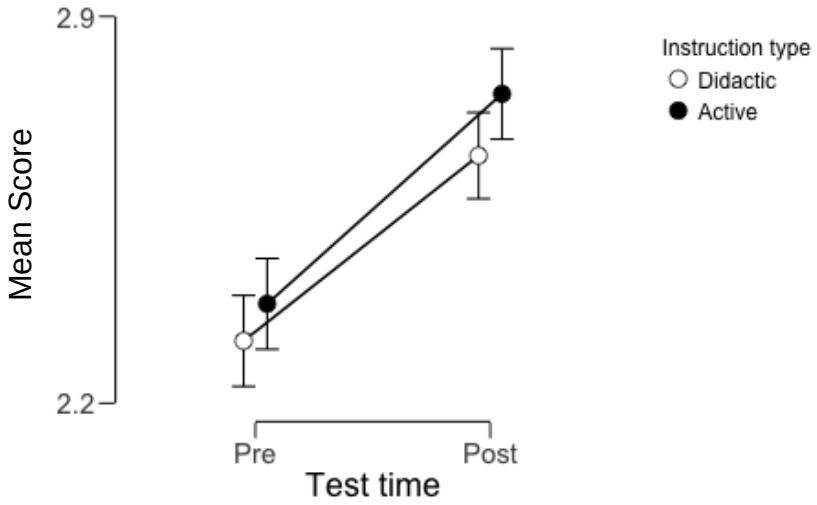


Figure 5.1 *Comparison of pre-test and post-test results between active learning and didactic tutorial*

Table 5.2
Comparison of pre-test and post-test results between active learning and didactic tutorial

Test time	Instruction type	*M*	*SD*	*N*
Pre-test	Didactic tutorial	2.313	1.072	179
	Active learning tutorial	2.380	1.246	179
Post-test	Didactic tutorial	2.648	0.985	179
	Active learning tutorial	2.760	1.153	179

Results of repeated measures ANOVA with Greenhouse-Geisser correction (Table 5.3), however, indicated that the type of tutorial, whether didactic or active learning, had no effect on the improvement of the students' conceptual understanding, $F(1,178)=.881$, $p=.349$, $\eta^2=.005$. Similar results were observed between the interaction of the two variables, conceptual test and tutorial type, $F(1,178)=.080$, $p=.777$, $\eta^2=.000$, suggesting that both tutorials caused conceptual improvement to the same degree. Full JASP statistical test outputs can be found in Appendix 8.

Table 5.3

Repeated measures ANOVA of students' conceptual pre-test and post-test scores in semester 1

Source	*df*	*MS*	*F*	*p*	η^2
Conceptual test	1	22.883	28.761	.001*	.139
Tutorial type	1	1.430	.881	.349	.005
Interaction	1	.089	.080	.777	.000
Residual	178	1.115			

**Significant at p<.05*

In contrast, results of second semester conceptual pre-test ($M=2.77$, $SD=1.19$) and post-test ($M=3.01$, $SD=1.16$) scores show no significant difference using dependent or paired samples *t*-test (Table 5.4), $t(93)=-1.62$, $p=.109$. Although there was 12.0% increase in learning gains of students, these results did not show a statistically significant increase in students' conceptual understanding after they were exposed to an active learning tutorial session.

Table 5.4

Paired samples t*-test of students' conceptual pre-test and post-test scores in semester 2*

	N	*M*	*SD*	*t*	*df*	*p*
Pre-test	94	2.77	1.19	-1.62	93	.109
Post-test	94	3.01	1.16			

A repeated measures ANOVA with a Greenhouse-Geisser correction (Table 5.5) also indicated no significant difference between the conceptual post-test scores of students exposed to a didactic tutorial (*M*= 2.648, *SD*=.985) and an active learning tutorial (*M*=2.760, *SD*=1.153); $F(1,178)=6.441\text{x}10^{-4}$, $p=.980$, $\eta^2=.000$. These results show that the conceptual understanding of students in the didactic and active learning tutorials were equivalent after the tutorials, confirming that both tutorials caused similar levels of conceptual improvement.

Table 5.5

Repeated measures ANOVA of student's conceptual post-test in semester 1

	df	*MS*	*F*	*p*	η^2
Didactic vs Active Learning	1	0.025	$6.441\text{x}10^{-4}$	.980	0.000
Residual	178	39.01			

Analysis of student engagement

Similar levels of self-reported student engagement were measured in both tutorial types. Repeated measures ANOVA with a Greenhouse-Geisser correction (Table 5.6) showed that there is no significant difference observed between the self-reported engagement rating (with a maximum rating of 50) of students exposed to a didactic tutorial (*M*= 30.4, *SD*=6.21) or an active learning tutorial (*M*= 30.5, *SD*=6.09), $F(1,178)= 6.44\text{x}10^{-4}$, $p=.980$,= $\eta^2.000$. These findings suggest that the students were moderately engaged in both didactic and active learning tutorials.

Table 5.6

Repeated measures ANOVA of student's self-reported engagement in semester 1

	df	*MS*	*F*	*p*	η^2
Didactic vs Active Learning	1	0.025	$6.44\text{x}10^{-4}$	0.980	0.000
Residual	178	39.03			

To drill down deeper, I categorised the statements in the EDL instrument as to behavioural engagement and affective-emotional engagement. Using repeated measures ANOVA with a Greenhouse-Geisser correction, I compared the behavioural engagement and

affective-emotional engagement of the didactic and active learning tutorials. Results (Table 5.7) show that there was no significant difference between the behavioural engagement rating of students exposed to a didactic tutorial and an active learning tutorial, $F(1,178)=.058$, $p=.810$, $\eta^2=.000$, as they were both very high.

Table 5.7

Repeated measures ANOVA of student's self-reported behavioural engagement

	df	*MS*	*F*	*p*	η^2
Didactic vs Active Learning	1	.715	.058	.810	0.000
Residual	178	12.37			

The same was observed with the affective-emotional engagement of the students. The results (Table 5.8) indicated that there was no significant difference between the affective-emotional engagement rating of students exposed to a didactic tutorial and an active learning tutorial, $F(1,178)=.073$, $p=.788$, $\eta^2=.000$.

Table 5.8

Repeated measures ANOVA of student's self-reported emotional engagement

	df	*MS*	*F*	*p*	η^2
Didactic vs Active Learning	1	1.01	.073	.788	.000
Residual	178	13.87			

The self-report engagement scale demonstrated that the students were equally engaged in both tutorials. However, the comments from the two independent classroom peer reviewers said otherwise. Independent observer 1 said that the "*students' focus was very high, providing insight to the level of cognitive engagement achieved,*" and "*…the instructional methods used succeeded in engaging students more actively with the content.*" In addition, independent observer 2 commented that "*student engagement increased*" in the active learning tutorial because it is "*more student-centered"* as the lecturer let the students *"work individually and [in] group[s].*"

The comments of the independent observers were further attested to by the data gathered by the two independent observers using the COPUS instrument as shown in Figures

1 and 2 (see Appendix 9 for data from each of the tutorial sessions). Figure 5.2 summarises the activities of the lecturer in the active learning and the didactic tutorials, whereas figure 5.3 summarises the activities of the students in each tutorial.

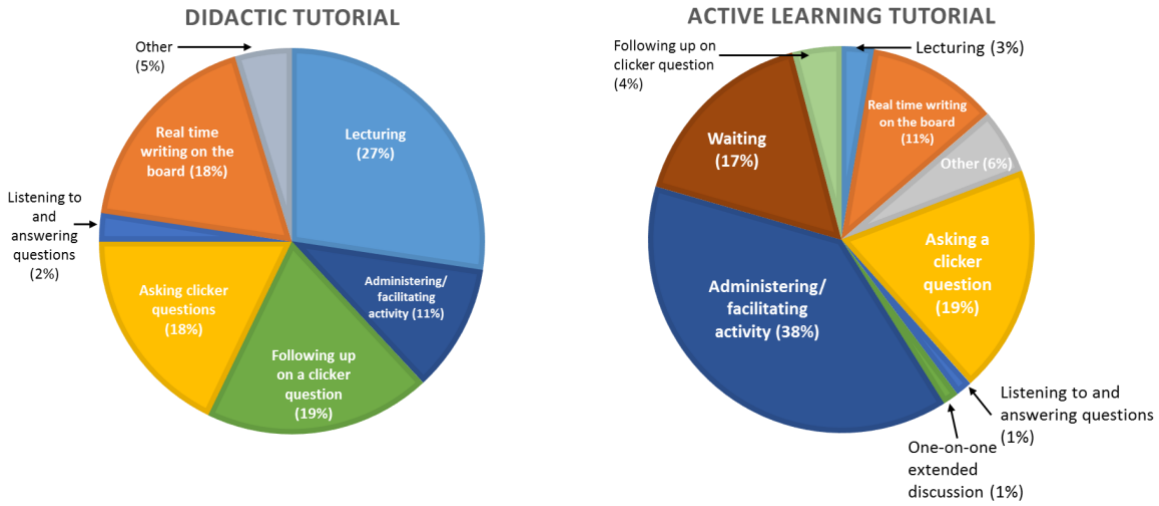


Figure 5.2 *What the lecturer was doing during each tutorial*

Figure 5.2 compares the didactic and active learning tutorials by showing a big shift from being teacher-centred instruction to 'teacher as a facilitator' instruction. The most dramatic difference is in the amount of time spent lecturing (27% in didactic, 3% in active learning), and the amount of time spent in administering or facilitating activities (11% in didactic, 38% in active learning). In the didactic tutorial the lecturer spent a total of 64% of the time talking, whereas in the active learning tutorial the lecturer spent a total of 26% of the time talking.

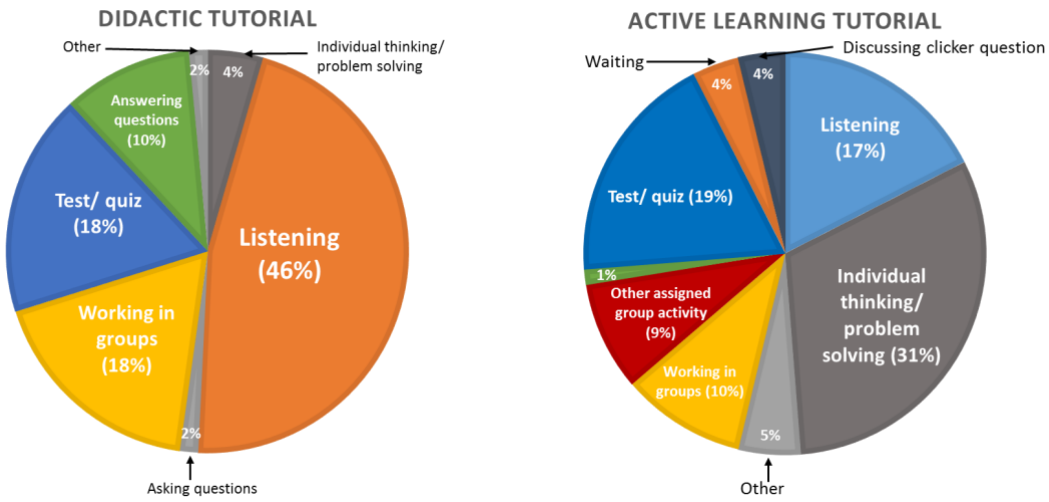


Figure 5.3 *What the students were doing during each tutorial*

Figure 5.3 compares the didactic and the active learning tutorials, showing a switch from passive learning to a student-centred class. It is clear that in the didactic tutorial, almost half of the class period (46%) was spent on listening. In contrast, class time period in the active learning tutorial was spent on individual thinking or problem solving (31%) while the students are working on the intentionally flawed manuscripts. In total, in the didactic tutorial, students spent 32% of the time was spent on student's solving problems, compared to 54% of the time in the active learning one.

The time spent in working in groups was different: 18% in the didactic tutorial and 10% in the active learning tutorial. It seems that the students did more group work in the didactic tutorial. However, while it seems that the students in the active learning tutorial spent only 10% of the class period working in groups, another category was observed by the observers, that is, 9% of the class period was spent in doing other assigned group activities, such as responding to non-clicker questions. In total, 19% of the class period in the active learning tutorial was spent in group work. Note that the amount of time spent in taking a quiz or a test was similar for both tutorials because the students answered the same pre-tests and post-tests.

Discussion

On the delivery of the didactic and the active learning tutorials

It was expected that the students' conceptual understanding would be increased by the active learning tutorial more than by the didactic tutorial, but this was not what was seen. It seems that the similarity in improvement of the students' conceptual understanding and engagement can be attributed to the delivery of the tutorials. One of the independent observers commented that even though the tutorial was didactic, the lecturer "*provided a more in-depth explanation of biochemical processes using pictures and diagrams*" while the students "*were more involved in a discussion and were a bit more outspoken.*" Carpenter et al. (2013), Carpenter and Olson (2012), and Serra and Dunlosky (2010) argue that students understand the content better in a well-organised lecture, especially when it is delivered with the aid of visual representations. In one of the didactic tutorials, the observer commented that "*it was, without a doubt, the most interactive tutorial up to date, and there was a considerable increase in class participation, attention and confidence on the part of the students*." Research shows that when students are actively engaged in a lecture, learning gains increase as well (Moravec et al., 2010). Indeed, Cordova et al. (2014) argued that confidence is also beneficial to the process of conceptual change, particularly when the error or misconception is pointed out to the student. However, not all the didactic tutorials were interactive. One of the independent classroom

observers commented that the first didactic tutorial "*was a more traditional tutorial, closely resembling a lecture.*" Smith et al. (2005) and Knight and Wood (2005) argued that traditional lectures are often ineffective, due to a failure to motivate the students to engage in the meaningful intellectual experiences. It appears that the first didactic tutorial succeeded in its objective to be more traditional. However, it seems that the rest of the didactic tutorials were more interactive in nature. It should be noted that trial 1 didactic tutorial was designed by a more traditional teacher, whereas trial 2 tutorials were both designed by the lecturer who executed the experiment, who finds it hard to go back to a more didactic style. This circumstance might have compromised the study.

The active learning tutorials

It was also apparent that the active learning tutorials were very interactive. One of the independent reviewers commented that "*the instructional methods used succeeded in engaging students more actively with the content*" and that "*the first noteworthy improvement regards the depth of the feedback provided [to the students].*" Providing meaningful scaffolding with prompt and constructive feedback is important in a teaching strategy that intentionally perplex learners (Lodge & Kennedy, 2015) so that students can move to ZOC, where the cognitive disequilibrium is resolved (Lodge et al., 2018). Otherwise, it will bring frustration and/or boredom to students (D'Mello et al., 2014). Lodge et al. (2018) also emphasised the importance of student engagement, so that students will move to the ZOC. Consequently, improved learning outcomes result from high student engagement (Klem & Connell, 2004; Krause, 2007). It appears that the lecturer succeeded in achieving the objective of the active learning tutorial, which is to be more student-centred in focus.

On the design of the experiment and intentionally flawed texts

It can be inferred from the observations of the observers that both the didactic and active learning tutorials achieved their goals to help the students understand the content better. One factor that could have caused both tutorial designs to have a similar improvements of students' conceptual understanding and levels of engagement was the design of the intentionally flawed texts and the experiment itself. One of the student participants emphasised that their "*major criticism*" with trial 1 active learning tutorial is that "*there wasn't too much time to deliver much content*." Findings from Cordova et al. (2014) experimental study and Espinosa, Monterola, and Punzalan (2013) intervention study suggest that learning outcomes are dependent on the length of exposure to the intervention. This participant also added that "*there*

wasn't enough time to read the… piece of paper [intentionally flawed texts] that was given." It appears that the reading comprehension time was underestimated by the lecturer when they prepared the intentionally flawed text. Although there is no concrete evidence showing a linear relationship between the amount of time spent in reading a single text (e.g. single article or paper) and academic achievement, Carroll's (1963) 'model of school learning and time' could possibly shed light on this relationship. Carroll's (1963) model states that "a learner will succeed in learning a given task to the extent that [s/]he spends the amount of time that [s/]he needs to learn the task" (p. 725). Moreover, extrapolating from the meta-analysis of Lewis (2002), he suggested that the amount of time spent in reading and learning outcomes posit a linear relationship. Hence, I argue that the longer time spent reading a single article or paper would also result to better learning outcomes for the students.

The Trial 2 active learning tutorials appeared to have more appropriate timing than the Trial 1. One of the participants commented that "*week 11 (trial 2) was pretty good*" because the intentionally flawed texts "*were all a lot shorter*" so, "*there was enough time [to read the text]*." Another participant commented that "*the pieces were more well-written, and I think they had examples of things.*" Moravcsik and Kintsch (1993) said that well-written texts are better understood by the students than poorly written ones even though they have no or minimal prior knowledge about the topic. It seems that the lecturer produced quality intentionally flawed texts in trial 2; thus, it had good reception from the students. This participant also preferred trial 2 because "*not only did I know what kind of structure was going to be, but I also like the content that we went over as well.*" It seems that this particular student found the topic of metabolism more interesting than membranes and lipids. A meta-analysis by Prenzel and Krapp (2011) and Willson (1983) suggest that students have higher academic achievement when they are interested in the content. It also seems that this particular student benefited from being familiar with the structure of the tutorial, however, no previous literature was identified which supports this observation. Thus, I would extrapolate from the findings of Cordova et al. (2014) and Espinosa et al. (2013) that academic achievement and the length of exposure to the intervention are positively correlated. The length of exposure to the intervention potentially familiarises the students with the structure of the intervention, which in turn assist them in understanding the content better.

On response bias in student self-reported engagement

It is also worth noting that the students who completed the self-report are students who turned up in the tutorials; these students potentially have intrinsic motivation to learn. In

addition, the university where the experiment was conducted is a high achieving university (UoM, 2019); hence, it was expected that students would be intrinsically engaged. However, this was not the case as the students' self-reported engagement indicated moderate engagement only for both tutorial types. This finding is in contrast with the findings of Singh, Granville, and Dika (2002) that intrinsic motivation is a salient predictor of learning outcomes in science and mathematics. However, self-report instruments are very subjective; hence, its validity is always questionable (D'Mello et al., 2014; Hoskin, 2012). In this study, possible influences on the student self-reported engagement include: the student's honesty in reporting their emotions (Hoskin, 2012; Rasinski, Visser, Zagatsky, & Rickett, 2005), the student's ability to accurately answer an introspective question (Goleman, 1995; Hoskin, 2012), the student's varying interpretation or understanding of certain questions (Hoskin, 2012), the student's varying interpretation and use of scales (i.e. in a scale of 1-5, a 4 would be interpreted differently by different people) (Austin, Deary, Gibson, McGregor, & Dent, 1998; Balakrishnan, 1999; Hoskin, 2012), and the student's resilience in reporting negative emotions (Tourangeau & Yan, 2007).

Conclusions and Recommendations

In this study, I compared a misconception-driven active learning tutorial to a lectorial-driven didactic tutorial in terms of students' conceptual understanding and engagement. Results show that both tutorials caused similar levels of improvement on both variables being measured; thus, no significant difference was observed in this study. Despite the intervention having no statistical significance in enhancing students' conceptual understanding and engagement, the learning gains, however, suggest that the students in an active learning tutorial achieved slightly higher scores compared with the students in a didactic tutorial. Similar results were observed in student engagement using a classroom observation instrument. The students seem to be more engaged in an active learning tutorial than in the didactic tutorial. The literature demonstrates that high student engagement is a precursor to higher learning outcomes (e.g. Klem & Connell, 2004; Krause, 2007).

Due to time constraints, the post-test was immediately administered to the students. However, I suggest a redesign of the experiment by conducting both an immediate and a delayed post-test to see whether it would show that the active learning tutorial was more effective at achieving lasting conceptual change compared to the didactic tutorial. Findings of an intervention study in mathematics suggest that students exposed to a misconception-driven teaching approach achieve higher conceptual knowledge and have fewer misconceptions in a

delayed post-test (Durkin & Rittle-Johnson, 2012). I would also recommend recording the conversations of students in dyads and examine them to find out how students come up with their refutation to the intentionally flawed manuscript. According to Chan (2001), refutation of misconceptions and deep learning only occur when the students constructed their own questions and explanations which can only be examined using the transcripts in a peer discussion.

There is also room for improving the design of this intervention, as well as the intentionally flawed manuscripts. It would be good to see the effects of the intervention to student's conceptual understanding and engagement if it were implemented in the whole semester. Considering the findings from the examination of peer discussions in the design of the intentionally flawed manuscripts would be a good improvement for this study, too. Moreover, collaborative approach involving one or more other lecturers would likely improve the quality of the materials.

Chapter 6

General Discussion and Conclusions

The ease of access to declarative knowledge and factual information through the Internet has changed the way we teach STEM, as well as other higher education disciplines. STEM education used to put emphasis on the acquisition of factual knowledge; thus, direct instruction used to be a norm in teaching STEM, because it can cover the amount of required content within a limited time (Bransford et al., 2000; Hake, 1998; Walker & Jorn, 2007). However, in this post-truth era where fake news and distorted information impact the learning process, there is an increasing demand that education should promote critical thinking. In response, inquiry-based and metacognitive approaches in teaching science emerged where the emphasis is not solely on the acquisition of factual, declarative knowledge, but also on the skills necessary to critique information (e.g. Allen & Tanner, 2005; Kramarski & Mevarech, 2003; Loertscher, 2009). Active learning (e.g. conceptual change teaching) is one of the many approaches to teaching STEM that encourages students to think critically and promote self-regulation. Active learning, however, is rarely practiced in most higher education classrooms partly because of the issue of large class sizes.

Are disciplinary differences a block to innovation?

Science teaching has always been geared towards scientific research training (Neumann, 2001) because of the belief that science students will become scientists in the future. Thus, the culture, philosophies, and educational goals of the STEM disciplines is to train students in the systematic investigation of scientific theories and laws, as well as in the formulation and testing of hypotheses through experimentation. This belief that the STEM disciplines can only be taught in a particular way is strongly influenced by disciplinary differences in teaching (Becher, 1981; Lenze, 1995).

On the one hand, disciplinary differences in teaching can be a good thing because STEM academics train science students in the fundamentals of scientific research, which exposes students to meaningful real-life intellectual and practical experiences. These real-life experiences are said to be the foundation of accurate scientific knowledge and skills needed of a scientist such as critical thinking and process skills (National Research Council, 2007; Wright & Boggs, 2002).

However, it seems that disciplinary differences hinder academics to innovate and infuse active learning into their teaching practice. For example, instead of giving performance-based and authentic assessments, STEM academics often give lower order assessment questions (e.g. memorisation and application) (Braxton, 1995; Smart & Ethington, 1995) and also set higher-stakes assessments (Warren Piper et al., 1996) because of their belief that students need to acquire and master a certain set of learning competencies to be able to understand higher, more complex ones.

Science students would potentially benefit from a 'hybrid' approach to teaching STEM, that is, academics use active learning strategies and authentic assessments intertwined with traditional lecture methods to 'teach' threshold concepts and troublesome knowledge. The 'hybrid' teaching approach brings together the objectives of active learning without disregarding the goals of disciplinary differences. That is, students acquire high-level of conceptual knowledge because they are deducing concepts independently. The idea of a 'hybrid' approach to teaching science aligns with the dynamism of academic disciplines theory of Squires (1992), that is, disciplines evolve and adapt to the contemporary world.

Active learning methods, particularly teaching strategies that potentially generate cognitive disequilibrium between the learners' prior knowledge and incoming information, show considerable success in assisting students acquire conceptual knowledge and refute misconceptions (D'Mello et al., 2014; Lodge et al., 2018) through self-questioning metacognitive steps. However, in this type of approach, the learners need to be sufficiently engaged (Lodge et al., 2018), otherwise it will not translate to improved learning outcomes. Implementation of teaching strategies that intentionally perplex learners, however, is not a straightforward task for a majority of STEM academics as they are not trained in pedagogy. In effect, STEM academics find shifting from traditional teaching to non-traditional teaching very challenging, most especially in the context of large classes. Research suggests, however, that the level of educational experience or training and the success of a teaching approach have a linear relationship (Andrews et al., 2011). Thus, academics need to attend professional development programs and be exposed to new teaching initiatives to help them change their perceptions and beliefs on teaching and eventually implement active learning strategies properly and effectively (Bain et al., 1998; Kember, 1997b; Postareff et al., 2007, 2008).

Is the teaching-research nexus the way to go?

It seems that there are inconsistencies with what higher education institutions aim to achieve (i.e. to have a strong link between teaching and research) and their reward system.

While universities endeavour to attain a strong link between teaching and research (Clark, 1997; Crittenden, 1997), the current reward system of universities puts more value on research than teaching (Bernstein, 2008; Harris et al., 2008). In effect, the bulk of the workload of academics is devoted into doing their research projects and only a little of it is allocated to the preparation of materials for their classes (Ballantyne et al., 1999; Boyer et al., 1994). A review of the extant literature, however, suggests that active involvement in research does not necessarily translate into competence in teaching (see Hattie & Marsh, 1996; Pascarella & Terenzini, 2005; Ramsden & Moses, 1992). This led Stappenbelt (2013) to conclude that "the teaching and research activities of academics should be treated as unrelated entities." This conclusion was supported by a meta-analysis done by Marsh and Hattie (2002) leading them to hypothesise that "teaching and research excellence are independent constructs." This puts the teaching-research nexus to question.

A review of literature suggests different descriptions or definitions of the teaching-research nexus. Wuetherick (2009) synthesised the literature and came up with five thematic descriptions of the teaching-research nexus: (1) knowledge generated from research informs the content knowledge that a lecturer will deliver to the class, (2) research methods are taught to the students, (3) students are given research projects that are based on inquiry and problem-based learning, (4) students are being involved in a research project, usually as a graduate research student or as a research assistant, and (5) "academics engaging in pedagogical research, or the scholarship of teaching and learning."

In most descriptions of the teaching-research nexus, the emphasis is on the knowledge generated through scientific research or the research methods utilised in generating new knowledge (Wuetherick, 2009). However, teaching *per se* is a completely different area of research. Academics who are actively involved in research acquire broader content knowledge about their discipline, but not necessarily on teaching or delivering the content knowledge in their discipline. It seems that the success indicators for the research component of the teaching-research nexus have been overly highlighted while the teaching component has been downplayed or even neglected. Thus, I argue that the most relevant definition of the teaching-research nexus would be the fifth in the above list, academics who are actively researching the best pedagogical approaches to deliver content to students.

Adapting an active learning approach is one thing, implementing it accurately is another thing. Some active learning approaches are not straightforward and will require sufficient training to understand their theoretical underpinnings to be able to execute them properly in class. Take for example, conceptual change teaching. Without proper training, an academic

may neglect essential components of the approach, such as formulating teaching materials that will induce cognitive disequilibrium at the same time as keeping students engaged throughout the learning process. Academics who are actively researching on pedagogy would have a greater grip of active learning strategies and are more likely to ensure positive learning outcomes for the students (Michael, 2006). This argument is also supported by Gibbs and Coffey (2004) that the quality of teaching training is equally important as the content to be taught.

Would a teaching specialist or education focused role mitigate the challenges in the teaching-research nexus paradigm for STEM disciplines?

STEM disciplines are traditionally taught by scientists, engineers, and mathematicians, who, like other higher education academics, do not consider themselves as teachers, but as a member of their own discipline (Becher, 1989; Kember, 1997a). However, due to the expansion of higher education in the United States, a growing concern on the delivery of the STEM disciplines emerged seemingly (Rudolph, 1990). In response, between 1970s and 1990s academics who are trained in the traditional STEM disciplines started to explore better ways to teach undergraduate subjects (National Research Council, 2012a). This endeavour has given birth to what is now known as 'discipline-based education research' (DBER) (National Research Council, 2012a). It should be noted that DBER differs from the scholarship of teaching and learning (SoTL) (Dolan, Elliott, Henderson et al., 2018). Although both areas have the same goal, which is to improve learning and teaching with the use of educational research data, the two differ in scope and reach. Dolan et al. (2018, p. 33) explain the difference between the two:

> "SoTL studies are typically descriptive and focus on innovations that address learning goals. Data collection and analyses are generally limited to one's classroom or program with the aim of making local improvements... In contrast, DBER pursues research questions and hypotheses about teaching, learning, and ways of thinking in a discipline that extend beyond single classrooms and programs in order to yield original, generalizable, and mechanistic insights into educational processes and their effects"

Both DBER and SoTL have gained recognition in the United States as emerging areas of research. It appears that DBER and SoTL could 'fill the gap' to the seemingly unclear association of teaching and research in the teaching-research nexus discussed in the previous section. DBER and SoTL academics teach undergraduate science courses informed by their

own research on the best pedagogical approaches to teach the STEM disciplines. Therefore, positive learning outcomes can be expected from their students.

Because of the important role of DBER and SoTL academics within the faculty of science, DBER academic positions have been created and the hiring of DBER academics continues to grow each year in the United States (Bush, Rudd, Stevens, Tanner, & Williams, 2016). In Australia, universities have been hiring teaching specialists or education focused academics over the past decade (Bennett, Roberts, & Ananthram, 2017; Rowland, 2012). These teaching specialists or education focused academics are assigned within the faculty of science to reduce the teaching load of research-active academics and sometimes to improve the quality of undergraduate STEM education. At present, it seems that it is becoming more common that these teaching specialists or education focused academics are being employed for both reasons. For this reason, some of them started embarking on SoTL and organising education research group within the faculty of science (e.g. Davis et al., 2012; Fildes et al., 2015; Rowland et al., 2012; Rowland et al., 2011). This interest of Australian teaching specialist academics could have prompted Rowland and Myatt (2014) to write a "how to" guide for science academics interested in SoTL [also referred to as Science Faculty with Education Specialties or SFES in other literature (e.g. Bush, Pelaez, Rudd et al., 2006; Rowland & Myatt, 2014)]. In addition, the Australian Conference on Science and Mathematics Education (ACSME) could also be a response of Australian STEM academics on the growing interest in improving teaching and learning in higher education. This growing interest of some Australian STEM academics in education research paved the way to establishing a journal entitled *International Journal of Innovation in Science and Mathematics Education (IJISME)*. This journal is "dedicated to encouraging and supporting early career researchers as well as academics in science and mathematics who are new to education research" (IJISME, 2019). The teaching specialist or education focused academic role could be the Australian equivalent of the American DBER position. However, it seems that the role of teaching specialists and education focused academic have not been laid out in detail. Thus, their role should be studied in greater detail to broaden and enhance our understanding of their contributions to the Australian higher education institutions.

In considering the role of DBER in Australian higher education, I argue that DBER experts are the best academics to tap in delivering professional development in education within their discipline (e.g. BCMB). These DBER academics would have a greater grasp of the content knowledge as well as a greater command of the appropriate pedagogy that are more likely to ensure a positive result.

Conclusions

In this thesis, I explored three distinct but closely related issues regarding teaching STEM for conceptual change. The first part explores the current pedagogical and curriculum design practices of a broad cross-section of biochemistry and molecular biology academics as a representative sample of the wider issue in STEM. This part also sheds light on how STEM academics cope with a large class setting and the impediments to infusing active learning into their classrooms. The second part unpacks the impact of the different characteristics of a learner, such as prior knowledge and confidence in prior knowledge, to the degree (whether strong, moderate, or weak) of conceptual change learning. This part also describes the ideal classroom conditions for conceptual change to occur. The third part explores the effectiveness of an active learning intervention, which was developed based on the ideal conditions for conceptual change, compared with a more traditional tutorial, in enhancing students' engagement and conceptual understanding. This part also accounts for the importance of student engagement in a learning environment that is anchored on the ideal conditions for conceptual change.

STEM academics have limited pedagogical training

The first issue raised in this thesis is the lack of formal education training of a majority of biochemistry and molecular biology academics. This inadequacy seems to translate into the traditional practices they employ in the classroom, wherein their primary, if not the only exemplar in teaching, are their teachers when they were undergraduates themselves. The problem with this kind of model is that most academics think that their discipline can only be taught in a particular way, hindering them to embrace the best pedagogical and curriculum practices based on the latest research in education. In response to the changing nature of students and the expansion of higher education, however, some academics started to engage in professional development for teachers. As a result, some academics tried to integrate active learning into the curriculum, and they also adjusted their teaching methods to suit a large class setting. Even though professional developments adjusted their teaching, the teaching remains predominantly traditional. A review of the extant literature presented in this thesis suggests that the success of a teaching approach lies on the level and the quality of education training of academics. However, this impediment remains a primary problem amongst STEM academics to engage fully in 'teaching for conceptual change.'

Roles of cognition and affect in conceptual change learning

The second issue raised in this thesis is the importance of mediating affective factors, such as confidence in prior knowledge, together with cognitive factors, such as prior knowledge, to ultimately achieve conceptual change. In this thesis and in other research in the learning sciences, it was revealed that confidence in prior knowledge has an impact in changing the student's mind and in conceptual change learning. The confidence in prior knowledge predicts whether a student will change their mind or not, as well as whether they will detect an error or a misconception or not from incoming information. The challenge, however, is developing self-regulation skills amongst the students. It appears that only the students with sufficient self-regulation skills, such as metaconceptual awareness, would be able to recognise when a state of disequilibrium is occurring. Therefore, it is imperative for academics to integrate active learning that potentially develops or enhances self-regulation skills of students. With this, we go back to my previous point that academics need to embrace conceptual change teaching to promote better learning outcomes for students. It also appears that for the learning process to ultimately lead to conceptual change, the responsibility does not only depend on the improved pedagogical practices of academics but also on the students themselves. The students need to develop self-regulation skills to be able to reflect on their own understanding and become more metaconceptually aware to recognise a potential state of cognitive disequilibrium.

Roles of student engagement in conceptual change learning

The third issue raised in this thesis is the importance for students to be sufficiently engaged in a teaching approach that intentionally perplex learners (e.g. a misconception-driven tutorial) so they can move to the zone of optimal confusion and eventually achieve conceptual change. A large body of literature presented in this thesis suggested that increased engagement leads to better learning outcomes for the students as well. However, when students experience persistent cognitive disequilibrium while connecting their prior knowledge to an incoming information, they will potentially get frustrated and eventually disengage and move to the zone of suboptimal confusion. The key here is for the students to have sufficient metaconceptual awareness to detect a learning impasse. Again, we go back to my previous argument about the importance of developing self-regulation skills amongst the students.

Bridging the research – practice gap

Theories on conceptual change teaching have become more and more advanced through the years. However, the reality of teaching practice remains to be in a traditional transmissive form of teaching, which goes to show that a large gap between theory and practice still exists. The dissemination of the present research on how science should be taught remains a compelling impediment to success of the conceptual change research. Thus, research on conceptual change teaching should not only end when the research is published but should also reach teaching academics in universities. It is imperative that any research on conceptual change teaching should incorporate training programs to disseminate research where it is most needed - the actual classrooms.

In addition, most science academics believe that science should only be taught in a certain way, in a way that they were also taught, for it to have good results for the students. Hence, there is a gap between what is being practiced in a normal classroom and the literature on conceptual change research. To bridge this gap, professional development projects for science academics should be instituted. These professional development projects should address both the pedagogical knowledge and pedagogical content knowledge of STEM academics. Trainings on pedagogical knowledge should focus on conceptual change approaches, while trainings on pedagogical content knowledge should focus on utilising research on conceptual change in teaching specific contents in the STEM disciplines.

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Appendix 1: Interview protocol for biochemistry and molecular biology academics

1. What type of classes do you teach? Describe a typical lesson in your classes, from the moment you walk in to the end. (Type of classes: lecture, tutorial or practical)
2. What are your views about the use of textbooks? Can you describe your use of textbooks?
3. What content do prospective Biochemistry and Molecular Biology majors need compared to other majors? How does the content differ and how do you address the difference?
4. How do you adjust to content when the class is composed of students from different background? What's the basis of that decision? Does this affect your teaching approach?
5. How much do you expect students to do work outside class and what usual form does it take?
6. What teaching resources are available, how do you use them and what are their limitations?
7. Are you aware of some students with learning disabilities? Can you please describe these students?
8. How do you deal with special students in the class who are not learning as fast or have special needs? What do you do with students who fall behind? Do you have intervention plans for these students? Please elaborate.
9. In your teaching, how do you relate concepts in Biochemistry and Molecular Biology to the real world and to other subjects? What are the advantages and limitations to this approach?
10. How do you try to encourage higher order thinking in the students? How do you try to achieve it in both teaching and assessment?
11. What typical assessment do you use in your classes and how often do you assess? What determines type of assessment and what are its advantages and limitations?
12. How do you provide feedback to students after assessing them? What's the timeline of feedback and what determines the timeline?
13. Do you use the concept of formative and summative assessments in designing your assessment tools? When do you use formative and summative assessments?
14. Do you use formative activities such as tutorials, case studies and online teaching?
15. What do you think of non-test based summative assessment? Do you think it is used enough? Why or why not? (Non-test assessment: practice exercises, case studies, problem-based learning, projects, portfolios, presentations, essays, etc.)

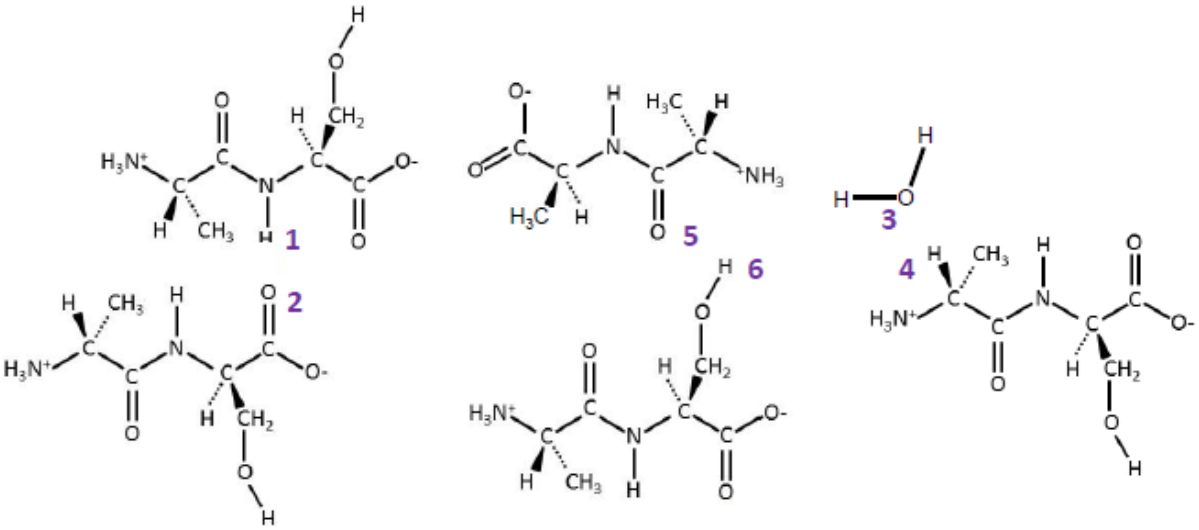
Appendix Table 2: Productive pedagogies dimensions and research questions

Dimension	Components	Research Questions
Intellectual Quality	Higher order thinking	To what extent do students use higher order operations?
	Deep knowledge	To what extent is deep knowledge presented?
	Deep understanding	To what extent is deep understanding evident?
	Substantive conversation	To what extent is classroom discourse devoted to creating or negotiating understandings of subject matter?
	Knowledge as problematic	To what degree is knowledge presented as constructed?
	Meta-language	To what extent does the teacher (or the students) talk or discuss explicitly how language works, aspects and characteristics of languages, texts and discourses?
Connectedness	Background knowledge	To what degree are links with students' background knowledge made explicit?
	Connectedness to the world	To what extent is the lesson, activity, or task connected to competencies or concerns beyond the classroom?
	Problem-based curriculum	To what extent is the lesson based on the solution of a specific problem(s)?
	Knowledge integration	To what degree is school knowledge integrated across subject boundaries?
Supportive Classroom Environment	Student direction of activities	To what degree do students determine the classroom activities?
	Explicit criteria	To what degree are criteria for what counts as high quality student performance made explicit?
	Social support	To what extent is the classroom characterised by an atmosphere of mutual respect and support among teacher and students?
	Academic engagement	To what extent are students engaged in the lesson?
	Student self- regulation	To what degree is classroom behaviour guided by implicit (self) control?
Valuing and Working with Difference (Recognition of Difference)	Cultural knowledges	To what degree are non-dominant cultural knowledges valued?
	Group identities	To what degree is the class a supportive environment for the production and positive recognition of difference and group identities?
	Representation	To what degree are non-dominant groups represented in classroom activities?
	Narrative	To what extent is narrative used for teaching and learning purposes in the lesson?
	Active citizenship	To what degree is the practice of active citizenship evident?

Adapted from Mills and Goos (2007)

Appendix 3: Biochemistry sample tutorial questions
(Note: Questions are parallel to Villafañe, Bailey, et al. (2011) POGIL Biochem Diagnostic Assessment Instrument)

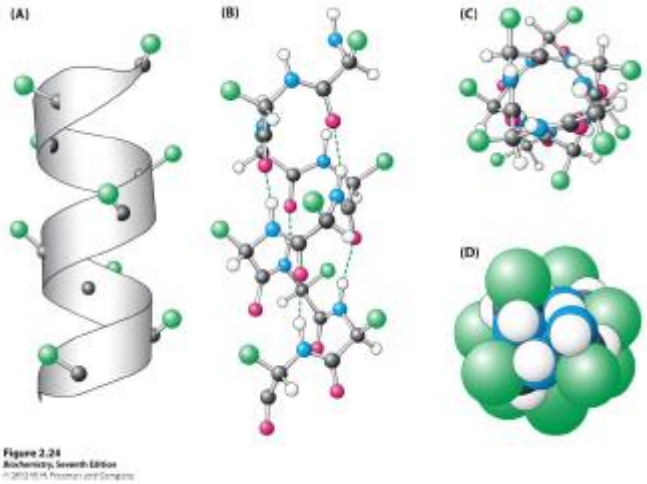
Question 1: In the drawings below, which pairs of atoms are involved in hydrogen bonding? The electronegativity values are: H=2.1; C=2.5; N=3.1, O=3.5



A. (1,2)
B. (1,2) & (3,4)
C. (3,4) & (5,6)
D. (1,2) & (5,6)
E. (1,2), (3,4) & (5,6)

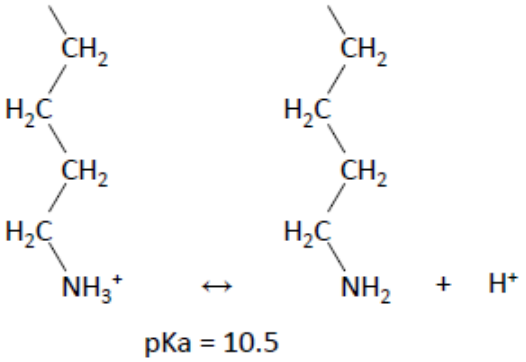
Question 2: Which statement about alpha-helices is true?

A. The side chains project inwards filling the central axis.
B. The interior of an alpha-helix can be filled with water or other small molecules.
C. Each alpha-helix is unique and has a different diameter.
D. The backbone atoms approach closely filling the interior of the helix.
E. Alpha-helix formation is stabilised by salt-bridges between backbone NH and C=O groups.



Question 3: If the pKa of an amine group is 10.5, which statement is correct?

A. At pH = 5, the predominant charge state will be negative.
B. At pH = 7, the predominant charge state will be positive.
C. At pH = 10.5, the predominant charge state will be neutral.
D. At pH = 14, the predominant charge state will be negative.
E. The predominant charge state of the group depends on base strength, not on pH.



Appendix 4: Molecular biology sample tutorial questions

Question 1: Which of these DNA sequences is most likely to be recognised by a typical eukaryotic transcription factor?

A. 5' AGCCTTGAAGTTCCGA 3'
B. 5' AGCCTTGTAGCCTTGT 3'
C. 5' AGCCTTGTACAAGGCT 3'
D. 5' AGCCTTGTTCGGAACA 3'

Question 2: I am amplifying the following DNA sequence using PCR. Only the ends of the sequence are shown.

5' AGCTTCTATCACATTCTGAATT……ATCCCTCCCGCGCAGGAACT 3'
3' TCGAAGATAGTGTAAGACTTAA..……TAGGGAGGGCGCGTCCTTGA 5'

Which of the following primer pairs will amplify this DNA?

A. 3' TCGAAGATAG 5' and 5' CGCAGGAACT 3'
B. 5' AGCTTCTATC 3' and 3' GCGTCCTTGA 5'

Question 3: I am amplifying the following DNA sequence using PCR. Only the ends of the sequence are shown.

Which of the following primer pairs will amplify this DNA?

A.
5' AGCTTCTATCACATTCTGAATT……ATCCCTCCCGCGCAGGAACT 3'
3' TCGAAGATAG 5'
5' CGCAGGAACT 3'
3' TCGAAGATAGTGTAAGACTTAA……..…TAGGGAGGGCGCGTCCTTGA 5'

B.
5'AGCTTCTATCACATTCTGAA**TT……ATCCCTCCCGCGCAGGAACT 3'**
3' GCGTCCTTGA 5'
5' AGCTTCTATC 3'
3' TCGAAGATAGTGTAAGACTTAA…..……TAGGGAGGGCGCGTCCTTGA 5'

Question 10: What is most likely to happen if there is lactose present but no glucose present?

A. The lacI repressor binds but the CAP protein doesn't, and there is low transcription of the *lac* operon
B. The lacI repressor doesn't bind but the CAP protein does, and there is high transcription of the *lac* operon
C. The lacI repressor doesn't bind but the CAP protein does, and there is low transcription of the *lac* operon
D. Neither the lacI repressor nor the CAP protein bind, and there is high transcription of the *lac* operon
E. Neither the lacI repressor nor the CAP protein bind, and there is low transcription of the *lac* operon

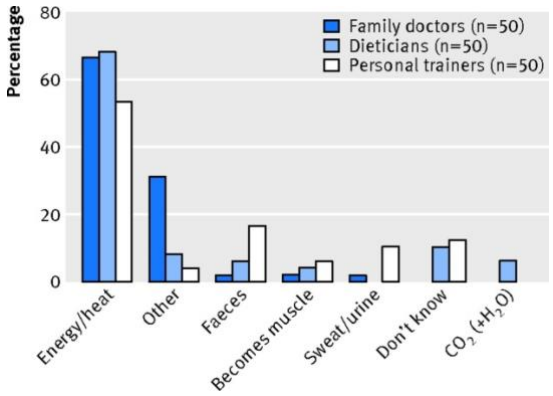
Question 11: What is most likely to happen if there is lactose present and glucose present?

A. The lacI repressor binds but the CAP protein doesn't, and there is low transcription of the *lac* operon
B. The lacI repressor doesn't bind but the CAP protein does, and there is high transcription of the *lac* operon
C. The lacI repressor doesn't bind but the CAP protein does, and there is low transcription of the *lac* operon
D. Neither the lacI repressor nor the CAP protein bind, and there is high transcription of the *lac* operon
E. Neither the lacI repressor nor the CAP protein bind, and there is low transcription of the *lac* operon

Appendix 5: Sample intentionally flawed text

Where does the fat go?

Western society is in the grip of an obesity epidemic –just take a look around any Australian shopping mall food court. The challenges that result are complicated by conflicting social, political and biological factors. However, before we can even start to address the problem, we are confronted with the issue of misconceptions about how humans lose weight, not just among the general public, but among those we look to for advice and guidance: family doctors, dieticians and personal trainers. The graph below shows the responses from these three groups to the question "When somebody loses weight, where does it go?"

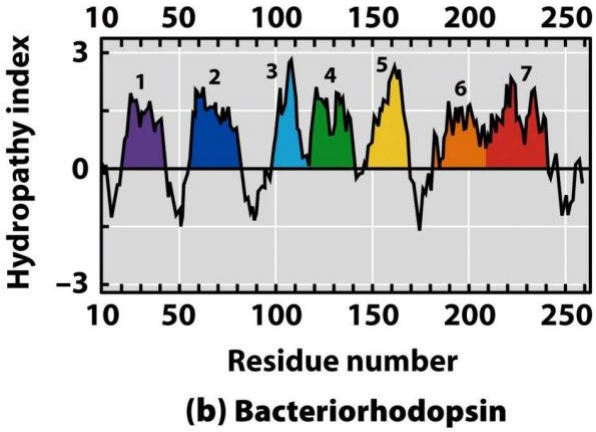


There seems to be a failure of our basic and tertiary science education: 65% family doctors, 70% dieticians and 50% personal trainers know that fat is converted to energy/heat. The rest suggest surprising variety of incorrect responses.

Appendix 6: Sample questions for conceptual pre- and post-test

Conceptual Pre-test

1. Given the information below:
   GLUT1 has a K_t of ~3 mM
   GLUT2 has a K_t of ~17 mM
   GLUT3 has a K_t of ~1.4 mM
   GLUT4 has a K_t of ~5 mM
   Which of the following statements is **CORRECT**?
   A. At 1.4 mM blood glucose, GLUT3 will be operating at its V_{max}.
   B. At 5 mM blood glucose, GLUT1, GLUT2 and GLUT3 will shut down and GLUT4 will take over.
   C. At 4 mM blood glucose, GLUT1 and GLUT3 will be operating below ½ V_{max}.
   D. At 5 mM blood glucose, GLUT3 will be operating closer to its V_{max} than GLUT2 will be.
   E. At 17 mM blood glucose, GLUT2 will be operating closer to its V_{max} than GLUT1 will be.
2. This is a hydropathy plot of the membrane protein bacteriorhodopsin. This diagram indicates that the plasma membrane of a cell:



(b) Bacteriorhodopsin

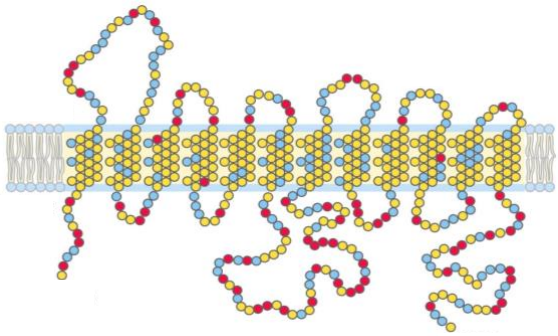
   A. is between 3 and 4 nm thick, because the negative peaks indicate the thickness of the inner leaflet and the positive peaks indicate the thickness of the outer leaflet.
   B. varies from 2 to 9 nm thick, because transmembrane helices vary from 15-60 residues long.
   C. is about 6 nm thick, because it is composed of two leaflets 3 nm thick, each of which can spanned by a transmembrane helix 20 residues long.
   D. is about 3 nm thick, because each transmembrane helix is about 20 residues long.

Conceptual Post-test

1. This diagram shows a schematic representation of the GLUT1 glucose transporter.

   Select the **most likely** locations for:

   CHARGED residues, POLAR residues and NONPOLAR residues, respectively.



   1. In contact with water, either inside or outside the cell.
   2. In contact with water, either or outside the membrane or lining the channel.
   3. In contact with the acyl chains of membrane lipids.
   4. Buried with other nonpolar residues in the hydrophobic core.

   A. 1, 2, 3
   B. 1, 2, 4
   C. 2, 1, 3
   D. 2, 1, 4

2. If an individual inherits an allele for the gene encoding the ABO blood group glycosyltransferases that contains a premature stop codon, it will result in expression of:
   A. the A type gene product, because the enzyme will recognise UDP-GalNAc instead of UDP-Gal.
   B. the B type gene product, because the enzyme will recognise UDP-Gal instead of UDP-GalNAc.
   C. the O type gene product, because the enzyme will be inactive.
   D. the AB type gene product , because the enzyme will recognise both UDP-GalNAc and UDP-Gal.
   E. the O type gene product , because the enzyme will recognise UDP-fucose instead of UDP-GalNAc and/or UDP-Gal.

Appendix 7: Short version of the engagement vs Disaffection with Learning: Student Self-report (Wellborn, 1991)

Please answer the following questions relating them to THIS tutorial.

1. When I'm in class, I just act like I'm working.
2. In class, I work as hard as I can.
3. When I'm in class, I participate in class discussions.
4. When I'm in class, I think about other things.
5. When I'm in class, I listen very carefully.
6. When we work on something in class, I feel bored.
7. When I get stuck on a problem, I feel worried.
8. Class is fun. – emotional engagement
9. When we work on something in class, I get involved.
10. When I can't answer a question, I feel frustrated.

[Answers will be in a 5 point likert-scale of Strongly Disagree – Strongly Agree]

Appendix 8 JASP Statistical test outputs

Data collected using the conceptual pre- and post-tests and engagement self-report were subjected to descriptive statistics and repeated measures (mixed-design) analysis of variance (ANOVA) using *Jeffreys' Amazing Statistics Program* (JASP). The conceptual pre- and post-tests consist of a 5-item multiple-choice questions while the engagement self-report is a 10-item Likert-scale questionnaire.

Repeated Measures ANOVA for Conceptual Pre- and Post-test

Appendix Table 8.1
Within Subjects Effects

	Sphericity Correction	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Test time	None	22.883	1.000	22.883	28.761	< .001	0.139
	Greenhouse-Geisser	22.883	1.000	22.883	28.761	< .001	0.139
	Huynh-Feldt	22.883	1.000	22.883	28.761	< .001	0.139
Residual	None	141.617	178.000	0.796			
	Greenhouse-Geisser	141.617	178.000	0.796			
	Huynh-Feldt	141.617	178.000	0.796			
Instruction type	None	1.430	1.000	1.430	0.881	0.349	0.005
	Greenhouse-Geisser	1.430	1.000	1.430	0.881	0.349	0.005
	Huynh-Feldt	1.430	1.000	1.430	0.881	0.349	0.005
Residual	None	289.070	178.000	1.624			
	Greenhouse-Geisser	289.070	178.000	1.624			
	Huynh-Feldt	289.070	178.000	1.624			
Test time ✻ Instruction type	None	0.089	1.000	0.089	0.080	0.777	0.000
	Greenhouse-Geisser	0.089	1.000	0.089	0.080	0.777	0.000
	Huynh-Feldt	0.089	1.000	0.089	0.080	0.777	0.000
Residual	None	198.411	178.000	1.115			
	Greenhouse-Geisser	198.411	178.000	1.115			
	Huynh-Feldt	198.411	178.000	1.115			

Note. Type III Sum of Squares

Appendix Table 8.2
Between Subjects Effects

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Residual	261.0	178	1.467			

Note. Type III Sum of Squares

Assumption Checks

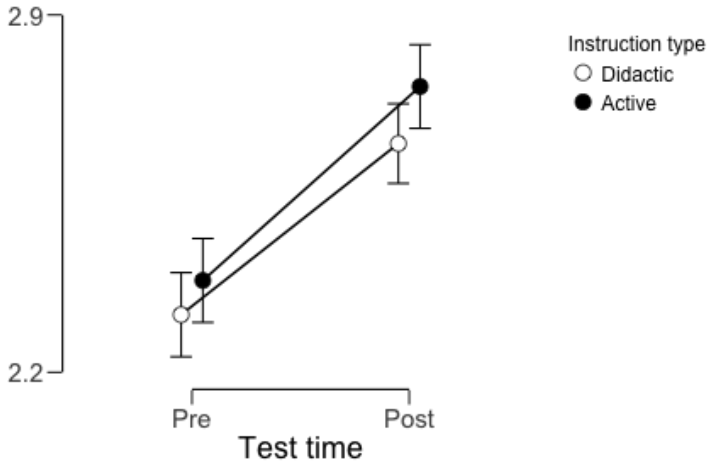
Appendix Table 8.3
Test of Sphericity

	Mauchly's *W*	*p*	Greenhouse-Geisser ε	Huynh-Feldt ε
Test time	1.000[a]	NaN[a]	1.000[a]	1.000[a]
Instruction type	1.000[a]	NaN[a]	1.000[a]	1.000[a]
Test time ✻ Instruction type	1.000[a]	NaN[a]	1.000[a]	1.000[a]

[a] The repeated measure has only two levels. When the repeated measure has two levels, the assumption of sphericity is always met.

Appendix Table 8.4
Descriptives

Test time	Instruction type	Mean	*SD*	*N*
Pre	Didactic	2.313	1.072	179
	Active	2.380	1.246	179
Post	Didactic	2.648	0.985	179
	Active	2.760	1.153	179



Appendix Figure 8.1. *Descriptives Plot*

Repeated Measures ANOVA for Conceptual Post-test

Appendix Table 8.5
Within Subjects Effects

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Instructional approach	0.025	1	0.025	6.441e-4	0.980	0.000
Residual	6947.475	178	39.031			

Note. Type III Sum of Squares

Appendix Table 8.6
Between Subjects Effects

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Residual	6533	178	36.70			

Note. Type III Sum of Squares

Assumption Checks

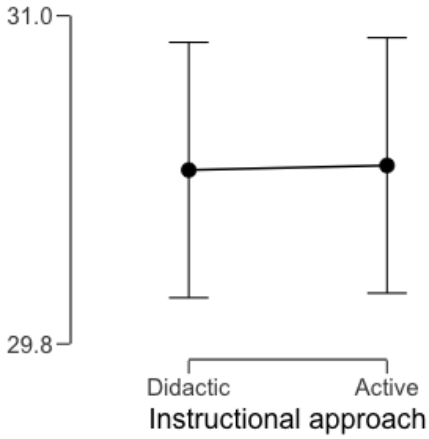
Appendix Table 8.7
Test of Sphericity

	Mauchly's *W*	*p*	Greenhouse-Geisser ε	Huynh-Feldt ε
Instructional approach	1.000[a]	NaN[a]	1.000[a]	1.000[a]

[a] The repeated measure has only two levels. When the repeated measure has two levels, the assumption of sphericity is always met.

Appendix Table 8.8
Descriptives

Instructional approach	Mean	*SD*	*N*
Didactic	30.44	6.214	179
Active	30.45	6.092	179



Appendix Figure 8.2 *Descriptives Plot*

Repeated Measures ANOVA for Engagement Self-report

Appendix Table 8.9
Within Subjects Effects

	Sphericity Correction	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Engagement	None	0.025	1.000	0.025	6.441e-4	0.980	0.000
	Greenhouse-Geisser	0.025	1.000	0.025	6.441e-4	0.980	0.000
	Huynh-Feldt	0.025	1.000	0.025	6.441e-4	0.980	0.000
Residual	None	6947.475	178.000	39.031			
	Greenhouse-Geisser	6947.475	178.000	39.031			
	Huynh-Feldt	6947.475	178.000	39.031			

Note. Type III Sum of Squares

Appendix Table 8.10
Between Subjects Effects

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Residual	6533	178	36.70			

Note. Type III Sum of Squares

Assumption Checks

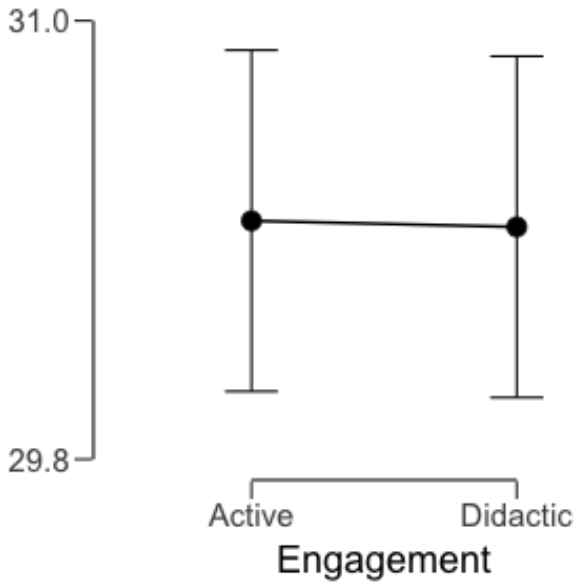
Appendix Table 8.11
Test of Sphericity

	Mauchly's *W*	*p*	Greenhouse-Geisser ε	Huynh-Feldt ε
Engagement	1.000[a]	NaN[a]	1.000[a]	1.000[a]

[a] The repeated measure has only two levels. When the repeated measure has two levels, the assumption of sphericity is always met.

Appendix Table 8.12
Descriptives

Engagement	Mean	*SD*	*N*
Active	30.45	6.092	179
Didactic	30.44	6.214	179



Appendix Figure 8.3. *Descriptives Plot*

Repeated Measures ANOVA for Behavioural Engagement Self-report

Appendix Table 8.13
Within Subjects Effects

	Sphericity Correction	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Behavioural Engagement	None	0.715	1.000	0.715	0.058	0.810	0.000
	Greenhouse-Geisser	0.715	1.000	0.715	0.058	0.810	0.000
	Huynh-Feldt	0.715	1.000	0.715	0.058	0.810	0.000
Residual	None	2202.285	178.000	12.372			
	Greenhouse-Geisser	2202.285	178.000	12.372			
	Huynh-Feldt	2202.285	178.000	12.372			

Note. Type III Sum of Squares

Appendix Table 8.14
Between Subjects Effects

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Residual	2142	178	12.03			

Note. Type III Sm of Squares

Assumption Checks

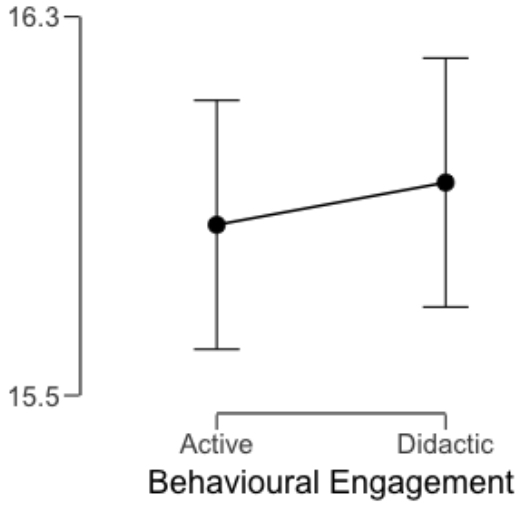
Appendix Table 8.15
Test of Sphericity

	Mauchly's *W*	*p*	Greenhouse-Geisser ε	Huynh-Feldt ε
Behavioural Engagement	1.000[a]	NaN[a]	1.000[a]	1.000[a]

[a] The repeated measure has only two levels. When the repeated measure has two levels, the assumption of sphericity is always met.

Appendix Table 8.16
Descriptives

Behavioural Engagement	Mean	*SD*	*N*
Active	15.86	3.304	179
Didactic	15.95	3.672	179



Appendix Figure 8.4 *Descriptives Plot*

Repeated Measures ANOVA for Emotional Engagement

Appendix Table 8.17
Within Subjects Effects

	Sphericity Correction	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Emotional engagement	None	1.008	1.000	1.008	0.073	0.788	0.000
	Greenhouse-Geisser	1.008	1.000	1.008	0.073	0.788	0.000
	Huynh-Feldt	1.008	1.000	1.008	0.073	0.788	0.000
Residual	None	2469.492	178.000	13.874			
	Greenhouse-Geisser	2469.492	178.000	13.874			
	Huynh-Feldt	2469.492	178.000	13.874			

Note. Type III Sum of Squares

Appendix Table 8.18
Between Subjects Effects

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Residual	2114	178	11.88			

Note. Type III Sum of Squares

Assumption Checks

Appendix Table 8.19
Test of Sphericity

	Mauchly's *W*	*p*	Greenhouse-Geisser ε	Huynh-Feldt ε
Emotional engagement	1.000[a]	NaN[a]	1.000[a]	1.000[a]

[a] The repeated measure has only two levels. When the repeated measure has two levels, the assumption of sphericity is always met.

Appendix Table 8.20
Descriptives

Emotional engagement	Mean	*SD*	*N*
Active	14.59	3.467	179
Didactic	14.49	3.706	179



Appendix Figure 8.5 *Descriptives Plot*

Appendix 9 Pie charts showing activities of the students and the lecturer from the COPUS instrument

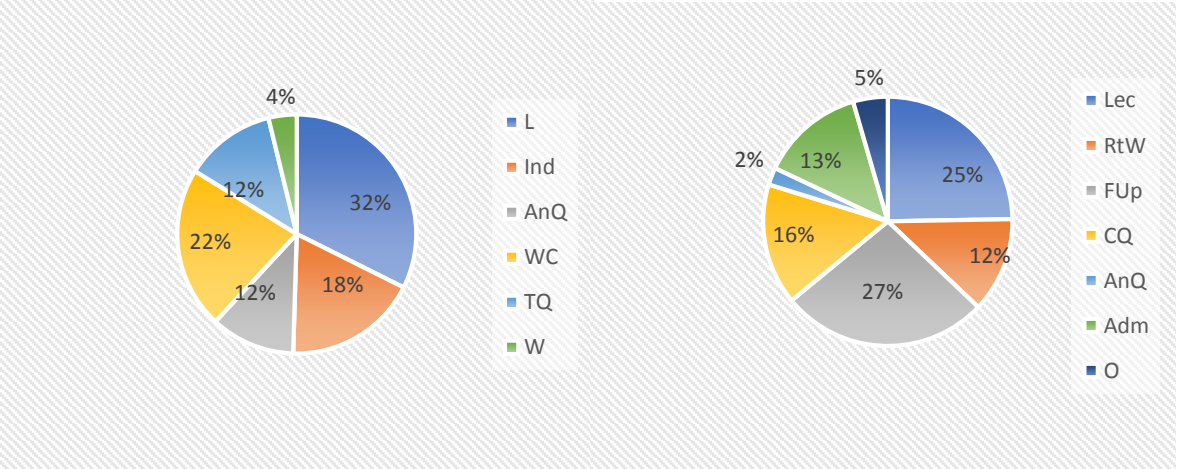
Data collected using the COPUS instrument were encoded in Microsoft Excel. The same software was utilised to generate pie charts, which compare the overall activities of the students and the lecturer in both the active and didactic tutorial. Appendix Table 9.1 shows the corresponding meaning of the abbreviated codes of the COPUS instrument used in the pie charts.

Appendix Table 9.1

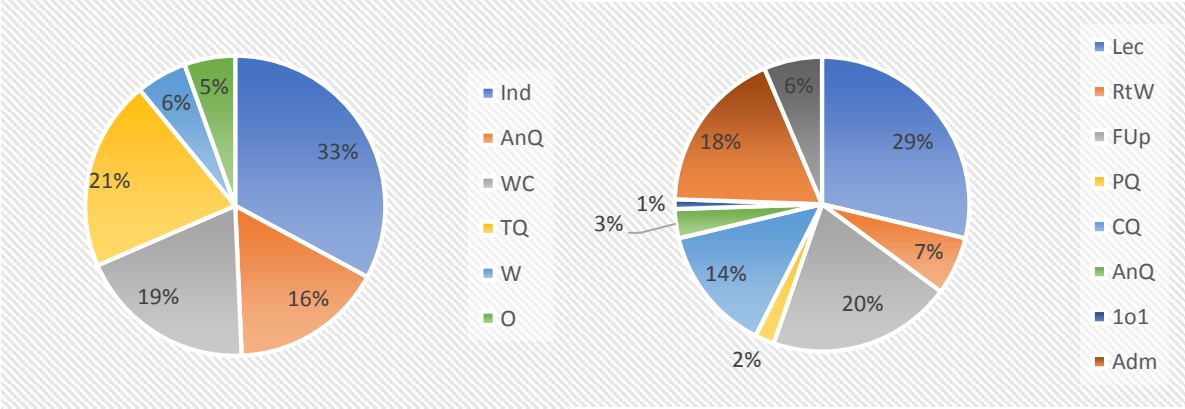
Abbreviated definitions of COPUS codes

Student codes		**Instructor codes**	
AnQ	Student answering instructor's question	PQ	Posing nonrhetorical, nonclicker question
SQ	Student asking a question	AnQ	Answering student question
CG	Discuss CQ in groups	CQ	Asking a clicker question (CQ)
WG	Work on worksheet in groups	FUp	Follow-up on CQ or activity
OG	Other group activities	W	Instructor waiting
L	Listening to instructor	Lec	Lecturing
Ind	Individual thinking/problem solving	RtW	Real-time writing on board, etc.
Prd	Making a prediction about a demo, experiment	MG	Moving through class, guiding work
WC	Whole-class discussion	1o1 with	One-on-one extended discussion student(s)
T/Q	Test or quiz	D/V	Showing/conducting a demo, experiment, etc.
SP	Student presentation	Adm	Administration
W	Students waiting	O	Other
O	Other		

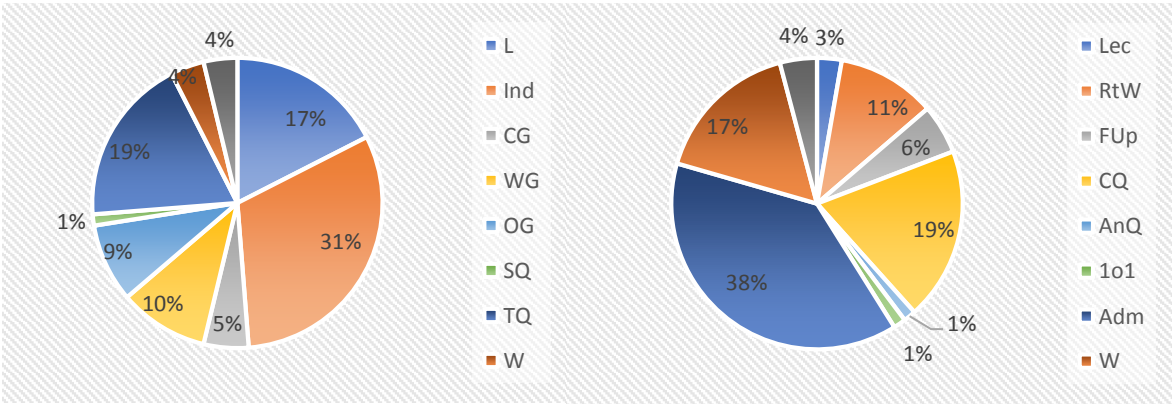
Adapted from Lund, Pilarz, Velasco et al. (2015)



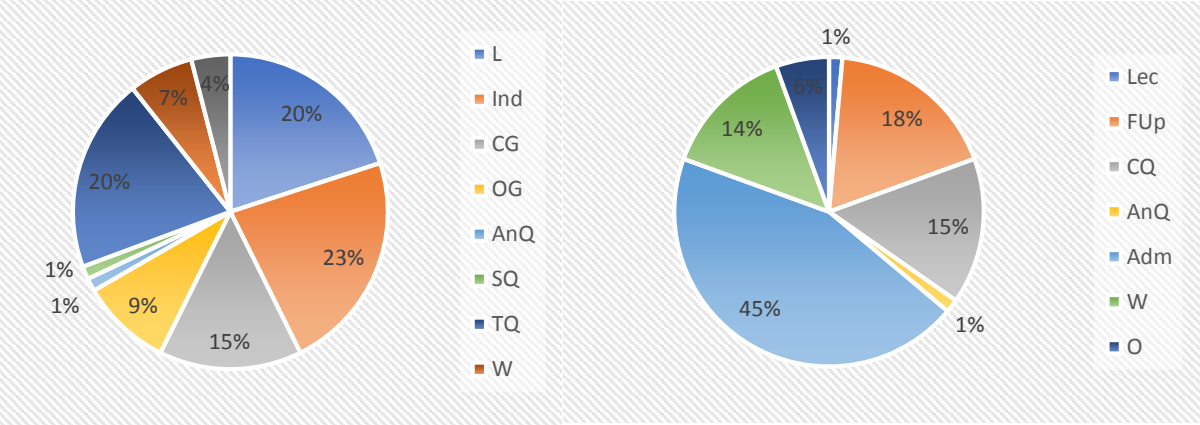
Appendix Figure 9.1. *Students' activities vs instructor's activities in a didactic tutorial (Trial 1, Session A)*



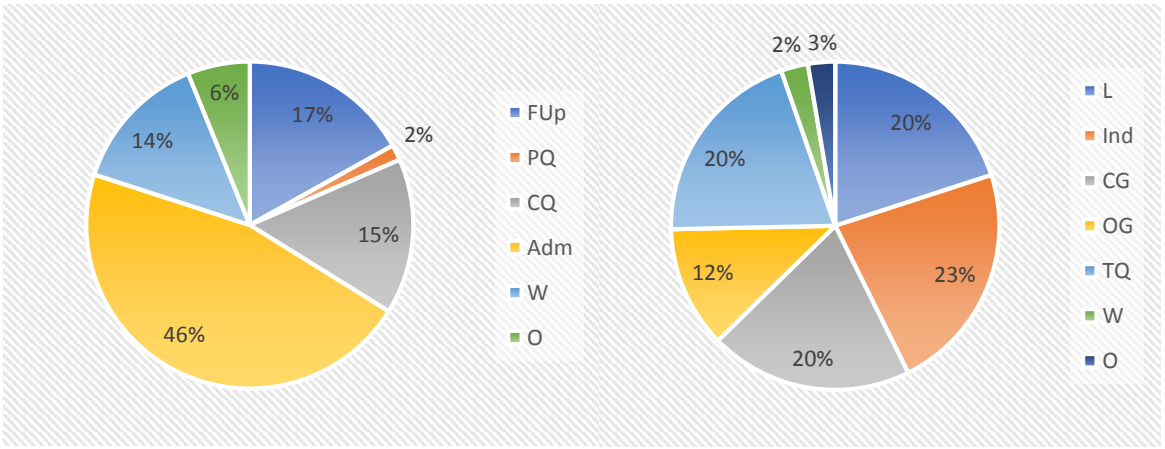
Appendix Figure 9.2. *Students' activities vs instructor's activities in a didactic tutorial (Trial 1, Session B)*



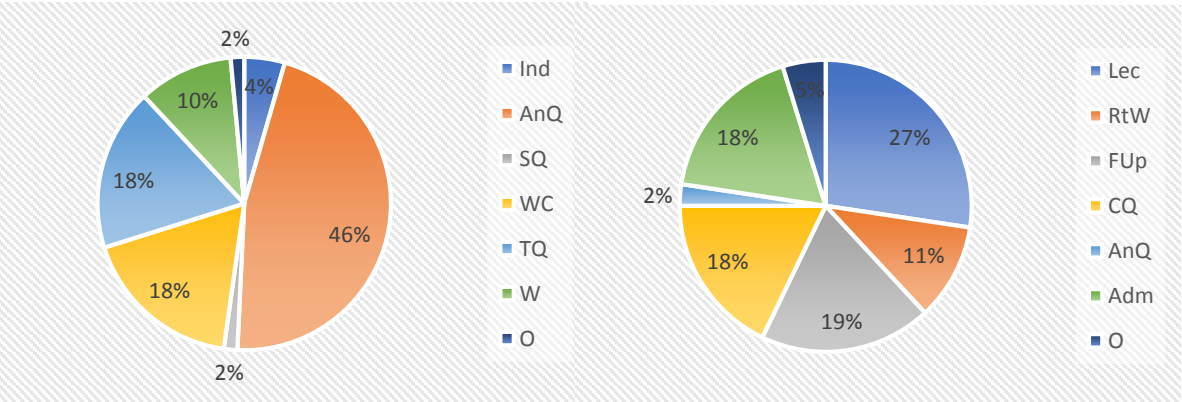
Appendix Figure 9.3: *Students' activities vs instructor's activities in an active learning tutorial (Trial 1, Session C)*



Appendix Figure 9.4. *Students' activities vs instructor's activities in an active learning tutorial (Trial 2, Session A)*



Appendix Figure 9.5. *Students' activities vs instructor's activities in an active learning tutorial (Trial 2, Session B)*



Appendix Figure 9.6 *Students' activities vs instructor's activities in a didactic tutorial (Trial 2, Session C)*