AN INVESTIGATION OF STUDENT LEARNING USING THRESHOLD CONCEPTS IN A FIRST YEAR CELL BIOLOGY COURSE

by

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Abstract

There is a lack of understanding of how conceptually difficult content is processed by students in first year biology courses. Much of the research reports that threshold concepts can be applied in multi-disciplinary frameworks from the sciences to humanities (Lucas and Mladenovic, 2007). By drawing on Land and Meyer's (2003) operational definition for threshold concepts, the purpose of this study is to investigate threshold concepts and their potential for high levels of student engagement in a first year cell biology course at the University of British Columbia. To investigate to what extent threshold concepts exist, student feedback with educators perspectives were examined for areas that represented threshold concepts and used to create a framework. Focus group interviews explored the student learning experience and evaluated if the course activities supported threshold concepts and provided a transformative learning experience. The transformative nature of concepts was related to levels of course engagement by administering a validated course engagement questionnaire to focus groups. The study showed there is some evidence of threshold concepts in cell biology, particularly in the areas of genetics and energy generation and focus group interviews corroborated these results. As three threshold concepts were chosen to examine in depth, discussions among focus group participants showed that students struggled with overcoming difficulties in understanding discursive language, linking concepts across the disciplines and distinguishing important concepts that are central to understanding biological processes. Two learning strategies that were found to be particularly useful in enhancing transformative learning were the use of in-class clicker questions and group investigation activities. However, students were assessed to be only moderately engaged in the content, relied on surface learning techniques for mastery and lacked the deeper learning processes that were necessary for a transformative learning experience. This study has implications for the role of instructional development to identify threshold concepts, help

students in learning challenging material and achieve deep learning processes. Based on these results, threshold concepts can provide the foundation for examining conceptually difficult content within a first year cell biology course and a specific focus on threshold concepts can assist student in crossing conceptual boundaries.

Preface

This thesis is based on work I completed as a Master's degree candidate in the Faculty of Education, Department of Curriculum and Pedagogy under the supervision of Dr. Harry Hubball. I was the primary researcher for this project and developed all protocols, focus group interview questions and activities as well as I chose relevant surveys. I was also a course instructor for Biology 112; Unicellular Life, at the University of British Columbia during this project and a member of the Department of Microbiology & Immunology. For focus group interviews and recruitment, I was assisted by an assistant, Michelle Buckner who is a graduate student in the Department of Microbiology and Immunology. Her assistance in the study was funded in part by the Dept of Microbiology & Immunology and the Science Skylight grant.

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Dedication

This thesis is dedicated to my family and friends for their constant support and encouragement.

To my friends, who were always encouraging and cheerful.

To both my parents, Lawrence and Joan, who always encouraged education and lifelong learning. In particular, I would like to make a special dedication to my Mother who, in spite of her terminal illness was extremely positive and inspiring. Thoughts of her praise during the most trying of times helped me move forward towards my goals. Although she did not make through to the end of the first year of my Master's degree, her spirit was always with me.

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1 Introduction

1.1 Background to the problem and context

Instructors at higher education institutions are encouraged to develop learning-centred approaches to teaching that is derived from contemporary perspectives of learning theory (Ambrose et al, 2010; Collins & Pratt, 2011; Haggis, 2003: Pang & To Ming, 2009; Perkins, 1999). For example, constructivist models in education draw upon social and active learning activities to engage students in the material in a deeper way (Beattie, Collins & McInnes, 1997; Hays, 2007; Morris & Puttee, 2006; Webb, 1997). What is not well understood and remains to be further examined in higher education is the process by which students obtain a deeper understanding of new knowledge. How they integrate this new knowledge into their previous experiences to create new "ways of knowing" (Perkins, 1999) is one area of on-going research (Brownlee, Walker, Lennox, Exley and Pearce, 2009; Giordano, 2010; Hazel, 2002; Palmer, 2005; Pugh, Linnenbrink-Garcia, Koskey, Stewart and Manzey, 2010).

Content which is conceptually more difficult and challenging for students is often referred to as "troublesome knowledge" (Land and Meyer, 2006). Using this idea of troublesome knowledge, Land and Meyer (2003) defined a type of conceptually difficult content entitled "threshold concepts". These concepts are different from core concepts in that they are transformative and according to the researchers can open up the students to new and deeper levels of understanding (Davies and Mangan, 2007; Ross and Taylor, 2010; Wilson and Akerlind, 2010). What is lacking in the research is empirical evidence as to how threshold concepts can be identified (if they exist), and how they can be used to transform student understanding.

Educators in life sciences are particularly interested in high levels of student engagement (Biggs & Tang, 2007; Floyd, Harrington & Santiago, 2009; Hazel, 2002: Ross & Taylor, 2006). The degree to which students are actively engaged in their learning is related to deep and surface learning processes (Anderberg, Alvegård, Svensson & Johansson 2009; Mellanby, Cortina-Borja, & Stein, 2009; Perkins, 1999). Educators acknowledge that students, at times, only understand the concepts in a surface approach to learning (Beattie et al, 1997; Hays, 2007; Morris et al, 2006). Depending on prior experiences, first year university students may rely on learning strategies that use only surface approaches such as memorization, mimicry and ritual knowledge (Perkins, 1999). Although surface learning approaches are a necessary part of the development to deeper processes, previous successes in this area may actually hinder students by preventing them to seek out deeper and more complex learning strategies. Therefore, in first year university, a transformation of learning approaches is often required to succeed in understanding more challenging concepts as students' progress through higher education (Reising et al, 2005).

First year university is an important transitional period for students who are attending a higher education institution for the first time (Barefoot, 2000). And so, there is increasing recognition to investigate and enhance the first year transition period (Brinkworth, McCann, Matthews & Nordstrom, 2009; Gurung, Weidert & Jeske, 2010; Kidwell & Reising, 2005; Pitkethly & Prosser, 2001). For example, a positive first year experience can drive a student's academic motivations and their ability to persist in the higher education culture (Kidwell et al, 2005). The ability to adapt can lead to the development of new learning strategies and thus the ability to learn at deeper levels. Conversely, students who adapt poorly to their first year experience tend to approach learning only at a surface level which is insufficient to be successful at university (Brownlee et al, 2009; Mellanby, 2009). Further, differences in perception between students and educators can lead to negative experiences. For example, despite various communication strategies, an educator’s views and expectations can be vastly different from those of students –even across the disciplines (Brinkworth et al, 2009). First year students typically have different expectations with respect to acceptable course workloads and whether they need to adopt new and effective learning approaches (Kidwell et al, 2005). Without adequate support in higher education, this can manifest itself in first year withdrawals due to a lack of adapting to new and demanding higher education environments; not intellectual difficulties (Pitkethly et al, 2001). The failure to acknowledge as well as provide adequate and effective learning support for transitional students can lead to an increase in university withdrawal rates (Pitkethly et al, 2001).

1.2 General problem area

There is a lack of understanding of how conceptually difficult content is processed by students in first year biology courses. Much of the research reports that threshold concepts can be applied in multi-disciplinary frameworks from the sciences to humanities (Lucas and Mladenovic, 2007). By drawing on Land and Meyer’s (2003) operational definition for threshold concepts, the purpose of this study is to investigate threshold concepts and their potential for high levels of student engagement in a first year cell biology course at University of British Columbia in the faculty of Science.

1.3 Research questions

Using the definition of threshold concepts by Land and Meyer (2003):

1. To what extent do threshold concepts exist in a first year cell biology course?

2. To what extent can threshold concepts engage students in transformative learning experiences in a first year cell biology course?

1.4 Methods of study

This study used a mixed-method approach to examining threshold concepts and the student learning experiences. To investigate the existence of threshold concepts (Question 1), the study used qualitative data provided from written student feedback from a first year cell biology course of 870 students. The feedback was based on a weekly, random sample of responses (10% or approximately 60 responses). The interpreted results were presented as a framework and three peer reviewers who were also educators in cell biology were asked to examine the framework and provide insight as to their interpretation of threshold concepts. Their feedback was used to establish consensus on threshold concepts in the course.

Quantitative and qualitative data analysis was used to address the student learning experiences in the course (Question 2). First a validated course engagement survey was administered to 25 students participating in focus group interview sessions of three to five students. The data was interpreted to quantify the level of engagement in this course. The learning experiences and assessment of difficult content by these students was obtained by focus group interview questions and discussions adding to the qualitative nature of the study.

1.5 Significance of problem area

Educators who teach first year students have different expectations as to course workload, study approaches and how learning occurs in university as compared to what first year students believe (Kidwell et al, 2005). Educators may be uninformed as to how the process of learning occurs and unable to recognize student mastery of a concept. Common testing methods such as assignments and exams may not test for conceptual understanding or a lack-there-of. Recognizing problem areas and ways to help students overcome these misunderstandings will inform university educators and provide them with tools to develop better learning objectives, assignments and activities for their courses.

1.6 Limitations of the study

This study will investigate a sub-set of students in a first year cell biology course at the University of British Columbia. The results of the study may be limited by the learning objectives and course content as well as the instructional techniques used to enhance the learning experience. Student participants were limited to those students who are attending university for the first time, in their first term at U.B.C. and are registered in the faculty of Science. Also, the number of students investigated was limited to 25 students among a course of >800 students.

2 Literature Review

2.1 Introduction

This literature review will examine an approach to defining conceptual knowledge called threshold concepts. I will discuss how a constructivist theoretical approach to learning has been aligned to threshold concepts and how these concepts differ from conventional course concepts or building blocks. In particular, I will demonstrate that there is a need to examine the first year student learning experience and suggest that understanding how difficult concepts are processed by these students is important for all educators at higher education institutions, particularly those who teach first year students. I will also examine how threshold concepts are currently being identified in various disciplines and explored in post-secondary education as tools for educators to approach knowledge that is difficult for all learners. I will review how some studies identified threshold concepts in the disciplines of economics, physics and biology and that this identification process was inherently problematic. In particular, I will focus on research that examined threshold concepts in the life sciences and how these authors purported that threshold concepts in biology led to the proposal of a new framework for learning in the life sciences. This review will also explore why the literature on threshold concepts is conflicted as to how to define and acknowledge a threshold concept and that a resolution is required to definitively present a theoretical framework.

2.2 Evolution of educational approaches

Educators at universities have traditionally distinguished themselves as vehicles to deliver knowledge. As approaches to education have evolved, methodologies in higher education have moved away from the transfer of information (filling the empty vessel theory) to facilitating the learning process (Ambrose, 2010; Biggs and Tang, 2007; Shulman 2008; Shulman, 1999). Educators and students are intricately linked in the process of learning. It stands to reason that any framework that aids the learning process can be utilized, advantageously, by both student and educator. When sciences are taught at higher education institutions, a constructivist approach is often adopted (Lundgren, 2010; Butler, Nakonechny, Nomme and Pollock, 2008; Hazel, 2004; Lee, 2002; Nelson, 2009; Smith and Cardaciotto, 2011). Constructivists assert that the learner creates and re-creates understandings by using their prior knowledge and experiences. The process of self-reflection with active and social learning activities yields a deeper understanding of the subject. What is not known or well understood is how this process occurs in the learner from an ontological perspective.

Concepts, presented as ideas and theories, are used to teach students new ideas and how to organize this new material. So, it is within this conceptual teaching approach that difficulties arise. Upon closer examination, we might ask how students process new knowledge. What are their ways of knowing and how do they assemble new information and integrate this with their own understandings? How are new ideas and theories deconstructed in the mind, and re-assembled into deeper understandings? How do misconceptions come about? To understand how we might become better educators, we must examine in detail what concepts are and how they are understood by the learner.

2.3 The first year student – A characterization

Students in their first year at university may be especially vulnerable to the challenges of learning at higher education institutions. These challenges are collectively referred to as the First Year Experience (FYE) and studies have shown that these students are often ill equipped for university life and its academic demands (Brinkworth, Brown & Schrader, 2009; McCann, Matthews & Nordstrom, 2009; Gurung, Weidert & Jeske, 2010; Kidwell & Reising, 2005; Pitkethly & Prosser, 2001). Globally, many higher education institutions offer a variety of programs for the FYE designed to supplement academic and life skills (Brown et al, 2008;

Brownlee et al 2009; NSSE, 2010). Although the needs that first year students bring to the university are often complex in nature, it is clear that these students lack the tools required to succeed academically. For example, studies have acknowledged that new learning and thinking strategies play a significant role in academic success. Yet, first year students tend to work individually and rely on existing skills rather than use new resources (Brown et al, 2009). Not only do higher education institutions need to address social and organization skills but also problems related to teaching and learning. According to the National Survey of Student Engagement in the U.S.A. (2010), Ikenberry wrote "What students know and are able to do—their ability to analyze complex issues, communicate effectively, and contribute to the welfare of society—has never been more important" (Ikenberry, S.O., 2010, p.4). Although these students are often ill prepared and face a reality shock in their first year, it is important that they take responsibility for their learning (Kidwell, 2005). In addition, other factors can add to the complexity of higher education such as an increase in class size (large classes) as well as the scale and speed which new material is covered (Barefoot, 2000). Thus, educators for first year students must implicitly focus their efforts on creating learning environments that support these students and assist the progression towards "learning the rules of the academic game" (Kidwell, 2005).

2.4 Concepts and conceptual integration

To engage students with the idea of language and theories within a discipline is to introduce information in the form of a concept. An educator in a higher education institution may describe concepts as ideas or mental representations or abilities (Rowbottom, 2007). For most subject matters, concepts serve as a system to categorize ideas and provide scaffolding for more complex theories (Perkins, 1999). While this definition appears to be straightforward, the reality is that many concepts are difficult to process and students do not fully engage in these concepts in a meaningful way. Taber (2008) explained that the degree of conceptual integration is important as it provides more meaningful learning and also is a characteristic of scientific knowledge. Therefore, it is imperative that science educators understand the basis for different types of knowledge and how this knowledge fits into theories of concepts. The research needs to show how types of knowledge that formulate deep and meaningful learning processes are distinguishable from surface learning (Taber, 2008).

2.5 Categorically difficult knowledge

The idea that knowledge and theories can themselves be categorized is examined and further explored by educational researchers Cousin, Land, Meyer and Perkins. Knowledge was described as tacit, inert, ritual, foreign (alien) as well as conceptually difficult. All contributed to issues in cognitive organization which is categorized by the authors as troublesome knowledge. It is this troublesome knowledge where Land and Meyer (2003) further characterized as a "Threshold Concept".

In any form, a conceptually problematic type of knowledge can block intellectual development (Land and Meyer, 2003). Perkins (1999) asked educators to question what types of constructivist approaches made sense to address learner difficulties. Perkins asserted that when educators incorrectly assume students understand the ideas and theories presented to them, to the educator, inert and ritual knowledge were the culprits. For example, in physics and mathematics, students used ritual knowledge like routine formulas and attempted to apply them to all problem solving situations without a deeper understanding of the theory (Land & Meyer, 2003; Perkins 1999). This invited and may have encouraged the learner to use mimicry rather than deeper applications (Cousin, 2006). When students in biology were asked to think about biological processes and, for example, how it can affect the theory of evolution, passive vocabulary was drawn upon and was used by the students (Ross & Taylor, 2006). This type of thinking lacked the necessary deep connection to the real world (Land, 2005; Perkins, 1999). This was described as inert knowledge which “sits in the mind’s attic” and is only unpackaged when called up. To address this problem, Perkins’ (1999) suggested that educators ask students to actively integrate their knowledge by using real connections to the world to become more meaningful. Perkins does not clarify, however, how this inert knowledge can have deeper meaning by applying to situational specific activities. Taber (2008) argues that learners find scientific knowledge difficult to integrate so surely there is not a simple application to remedy this issue in learning.

Land and Meyer (2006) explored the idea of categories of knowledge further by suggesting that the complexity of knowledge, that which is tacit (mainly personal and implicit) is inherently troublesome and results in unexplained understandings. This could mean that although students may use ritual and inert knowledge in a surface approach to learning, their tacit knowledge may not be explored as a tool to find deeper meanings to concepts. This led these researchers to consider foreign or alien knowledge as additional classes of knowledge that add to misunderstandings. Foreign knowledge was described as that which conflicts with one’s understandings and at times is not recognized by the learner (Perkins, 1999). One can think of this as counter-intuitive information which is influenced by students’ own intuitive beliefs and understandings. For example, a history student may lack the appreciation of what influenced historical decision-making processes that changed the world. The historical perspective could conflict with one’s modern day value systems. Thus, from early on, misconceptions can arise and interfere with the learner’s ability to use prior understandings and integrate this with the new knowledge.

Although these definitions of knowledge are helpful in a categorical manner, it is not clear how the issues of deeper understandings and misconceptions can be directly addressed. The authors offered only generalized solutions (more active learning, more problem solving). As learning is an ontological process (and so stated by the authors) there appears to be no clear methodology in driving student motivation to integrate ideas, challenge their previous understandings, and identify their own misconceptions. Land and Meyer (2006) further pointed out that this failure of students to integrate ideas is directly related to the integrative nature of their threshold concept theory. Perkins (1999) stated that this "process can also exert a high cognitive demand on learners and not all learners are able to respond to this" but continues to suggest constructivism as a toolbox for educational progress. As educators, do we unknowingly encourage students to use only ritual and inert knowledge because the learning activities we present to them only require this type of surface learning? Or do students lack the opportunity to present their own tacit, deeper understandings if it is present?

2.6 Threshold concepts in their categorical form

It appears that Land and Meyer used the operational definitions of knowledge (ritual, inert, tacit) to reinforce their theory of the existence of the threshold concept. Ironically, the idea of a concept being more than that of scaffolding is what led Land and Meyer (2003) to define a threshold concept. Threshold concepts are proposed to be distinct from functionally categorical concepts (e.g.ranking items) as they represent a transformed way of thinking and interpreting knowledge (Land, 2006). Threshold concepts have also been described as a heuristic for addressing difficult or troublesome knowledge (Cousin, 2006; Ross et al, 2006) and they offer to help educators with students who acquire knowledge but struggle with the underpinning theories and their applications in the real world (Davies & Mangan, 2005). This idea separates threshold concepts from categorizers in that threshold concepts represent an ontological shift (Cousin, 2006). Land and Meyer (2003) argued that most universities describe core concepts (i.e. Perkins (1999) "functional categorizers") as building blocks which do not necessarily lead to new understandings. Core concepts have to be understood at a basic level whereas threshold concepts will transform this understanding. In addition to both **transformative** and **troublesome**, the researchers further characterized threshold concepts as **irreversible** (unlikely to be forgotten), **integrative** (exposes previously hidden unrelatedness) and **bounded** (borders into new conceptual space).

2.7 Liminal states and conceptual integration

The key trait that distinguishes threshold concepts from functional categorizing type concepts is that threshold concepts are transformative and, once mastered, will shift a students' perception of a subject (Land, 2005; Cousin, 2006). Land and Meyer compared this shift to the opening of a "conceptual gateway" or "portal". Hence, the analogy of the threshold comes to mind as learners pass through or across a threshold as one would cross through a doorway.

The authors suggested that this passage may also guide behavior and result in a shift in personal identity (Land, 2003). The nature of this transformative process may cause a shift in one's values, attitudes and feelings. Once novice learners fully comprehend the underlying principles behind the concept, they move to a deeper understanding. Student behavior then transitions closer to that of an expert in the discipline. This becomes part of the identity of the learner and, therefore, can be transformative from an ontological perspective.

An ontological shift (or lack thereof) is explained by Land and Meyer (2003) in that learners enter a conceptual space called liminality. By definition, the word root or "limen" is translated from latin as a boundary. The result of crossing this bounded or liminal state is that the learner acquires new knowledge and a new identity. Kimchin (2010) concurred with the existence of a liminal state and referred to this as "conceptual stasis". The liminal state is a period of transition where the learner is experiencing thoughts that are indeterminate and ambiguous. This leaves the learner suspended between stages of learning. According to Land

and Meyer (2003), the learner, however, is open and accepting. Once a learner navigates through liminality, a sense of self-awareness and cognitive freedom occurs. The learner is now open to new ideas and the acceptance of theories. This is in agreement to Kinchin (2010) who entertained the idea that periods of stasis do not represent inactivity (or non-learning). It is a required part of the learning process to develop new knowledge structures. In the literature, there is a lack of understanding of what exactly happens in this state and therefore, none of the researchers describe any mental processes that may occur.

2.8 Discipline specific knowledge

Within higher education, the new identity a learner achieves can be thought of moving towards expert thinking (Perkins, 1999). This new status allows the learner to engage in discursive practices within the discipline and, therefore, proponents of the notion of threshold concepts maintained that crossing liminal states must be a discipline-specific passage (Land, 2003; Cousin, 2006). Although new understandings can be thought of as a passage through boundaries, any issues related to this journey may arise in the individual –not the subject. Given that this is a personal journey, is it possible for an educator guide students through liminal spaces by requiring students to perform specific tasks and apply knowledge in a discipline-specific manner?

Various threshold concept studies in economics, physics, and biology have used students' different interpretations to identify the presence of threshold concepts (Davies, 2005; Wilson, 2010; Ross, 2006) and all purported that re-designed activities, with support material, can allow for this passage. None of the studies, however, specifically conclude any one activity can do this. Hence, the identification of a threshold concept may be useful in targeting areas of troublesome knowledge; but there is a lack of action-based research where specific learning related exercises will resolve this.

2.9 Single framework or discipline specific?

Lucas and Mladenovic (2007) suggested this new perspective on a student's conceptual understanding (threshold concepts) can be used as a framework that can draw together various disciplines to develop better educative approaches rather than a discipline specific approach to educational practices. The authors focused on social reconstruction of the discipline by a central framework in threshold concepts. This contrasts with Perkins (1999), who argued that science concepts reflect underlying models and discipline-specific discourses. Perkins, however, is supported by Cousin (2006) and reiterated by Land and Meyer (2006) who describe an affective and social dimension to moving students through liminal spaces (ontological shifts) and warn educators against "disembodiment" of a concept. Therefore, examining the liminal state of learning must be done in a discipline-specific manner. It is not clear if a single framework using threshold concepts is either necessary or more important than approaching it from a subject related lens. Certainly, across the disciplines, all educators are concerned with improving curriculum and examining the nature of student's understanding. Clearly from the examination of the research, the idea of a "threshold concept" resonates among educators from accounting and economics to physics and biology. A single framework can be advantageous to educational developers when working with various discipline-specific experts (e.g. lecturers) (Cousin, 2006). However, there are a limited number of educational research studies that demonstrate a single framework can exist.

2.10 Recognizing threshold concepts

Land and Meyer (2005) put educators to task in that they suggest the sources of blockage in epistemological approaches may be identified by constructive feedback. Lucas and Mladenovic (2007) used an accounting example where lecturers identified threshold concepts by using student misconceptions but were conflicted as to which ones are threshold concepts or why they represented threshold concepts. This was similar to several studies in economics, biology and physics where even experts in the discipline appear to disagree as to which concepts represented building blocks or threshold concepts. Many of the authors proposed that a dialogue between students and educators is necessary to analyze where the troublesome concepts lie. Davies and Mangan (2007) acknowledged that determining what are "threshold concepts" is not a straightforward task and considered a framework that differentiated these from core concepts. As most educators in a subject area are not educational specialists, Cousin (2006) argued that experts in the disciplines can deconstruct their subject areas to become subject specialists without the fear of questioning their educational practices. At the most basic level, it is necessary for all educators to work together with students in identifying what appear to be threshold concepts that require mastery in the discipline. This will overtly call attention to areas where common conceptual difficulties exist (Cousin, 2006). One can deduce that consensus within the discipline is necessary. Educators may have trouble either identifying threshold concepts or accepting what defines a threshold concept. This is a conundrum in the research. Is the identity of a threshold concept a "threshold concept" for experts? The research is clear; identifying threshold concepts is not an easy task.

2.11 Threshold concepts acknowledged

For threshold concepts to have any impact in a course and provoke a change in curriculum, they must first be acknowledged and identified within a subject area. Current studies in physics, economics and biology have attempted to identify and use threshold concepts as model for curriculum reform. In all these studies, the researchers identified troublesome knowledge that has the potential for transformative thinking (Davies, 2007; Ross, 2010; Wilson, 2010). These concepts were obtained by surveying students and educators for misconceptions or by conducting student interviews. It is within these disciplines that I will examine how the identification of threshold concepts came about and what challenges were presented to develop a framework within the discipline.

One of the first studies to examine threshold concepts was in the field of economics (Davies, 2005). This early study explored different approaches to identifying threshold concepts and suggested a framework for how concepts can be understood. Davies and Mangan (2005) proposed that concepts can be categorized as three types of conceptual change; basic, discipline and modeling. Each represented a scale of transformational change and integration starting from a basic level to thinking within the discipline and lastly, modeling. The modeling term (the learner's ability to create theoretical models) was later changed to be called "procedural" to better exemplify the process of model construction (not just the ability to create models). This type of conceptual hierarchy was later adopted in a similar form by Ross and Taylor (2006) in biology. As Davies and Mangan (2003) recognized these conceptual categories as overlapping and linked in some form, they suggested that threshold concepts are made up of a web of concepts. Within the web, the concepts or constructs have different relationships to each other. The researchers also argued that although discipline and modeling conceptual changes represent thresholds, it was not clear if basic conception does. These are perhaps seen as key concepts or building blocks as they do not have a discipline-specific integration. It stands to reason, if threshold concepts are identified and viewed from the latter two of the three stages, a cross-disciplinary framework could not work as threshold concepts are drawn from a specific subject area and are thus discipline related.

The later study of Davies and Mangan (2007) attempted to demonstrate how threshold concepts can be integrated to develop a deeper understanding of economics by re-examining the data obtained from the first study. Four types of data were used to demonstrate the differences between expert and student thinking. In the first analysis, experts (educators) and students were asked to analyze a problem associated with concepts taught in first year economics. The researchers also examined relevant questions from exams, open-ended questions on economic analysis and a questionnaire what students' found most difficult. Expanding on the first study, the researchers concluded that transformative experiences are equated to shifts in disciplinary thinking and reinforced the idea of a web of concepts. It is clear that the researchers compared what expert thinking would be to that of the student. However, it is not clear that this evidence supports transformative thinking. For example, the study examined student responses which showed an attempt to use technical terminology and concluded that the lack of follow-through by the student may represent troublesome thinking. That is, students get stuck. One would question if this is equitable to a liminal state or a lack of understanding. Later, the authors state that their conclusions are tentative since the idea of threshold concepts are in the early stages of development.

In physics, "measurement uncertainty" was determined to be a threshold concept (Akerlind & Wilson, 2010). This is relatively new as compared to previously described laws of thermodynamics by Land and Meyer (2003). This study clearly states that there are a limited number of concepts that are threshold and asked physics educators from five universities in Australia to be subject experts. The educators identified several potential candidates for the threshold concept model and "measurement uncertainty" was chosen to examine further.

This concept was determined to be transformative in nature and found to fit into the threshold concept criteria as defined by the other four characteristics outlined by Land and Meyer (2003), (e.g. integrative, irreversible, bounded, troublesome). Drawing from the Davies and Mangan (2005) study, the educational developers asked the physics experts to describe common misunderstandings and from this, designed problems for further examination. Student responses were collected and interviews were analyzed for ways of understanding. This was compared to the misunderstandings from the experts. The researchers determined that student interviews were necessary to provide additional insights into student understandings. So, although student interviews were resource intensive, they were determined to be powerful in determining the barriers of conceptual change. This makes sense as student written answers to a physics problem would not provide the same insight as a student verbally interacting with their own learning process.

2.12 A model for threshold concepts in biology

What is most relevant to this paper is how threshold concepts are identified and used in the discipline of biology. Although, there appears to be a lack of studies that target cellular processes, Ross and Taylor (2006, 2010) had begun an examination of various concepts in first year biology. Ross and Taylor (2010) supported the three stage scale of Davies and Mangan (2007); basics, discipline, procedural. The researchers added another level, they called "pre-basic". This is where conceptual understanding begins at the pre-higher education level (e.g. secondary school or lower school). They also maintained that threshold concepts represent a web of concepts that are interconnected. What is most interesting is that Ross and Taylor (2006) added that thinking at the cellular level is inherently troublesome as most students have issues in thinking at the "submicroscopically". The students lack personal experience to draw up their knowledge in this manner.

The biology study used student misconceptions by analyzing data from a first year biology course using the concept of evolution and hypothesis testing. They also suggested that particular cellular processes such as energetic, dynamics and scale represent threshold concepts because they have been consistently identified as difficult knowledge although there was no specific data to show this. The biology experts, as with the economic educators, struggled to find consensus among the four threshold concepts characteristics that were appropriate to identify threshold concepts in this field. The strength in their argument lies in the discipline-specific conceptual scale (Davies, 2005). For instance, understanding biology requires discursive practices and the language of biology in itself is a threshold concept.

2.13 Conceptual struggles as threshold concepts

It appears that any areas of difficulty, misconceptions, and misunderstandings for students are most likely to be interpreted as a threshold concept. In “Demystifying Threshold Concepts”, Rowbottom (2007) represented an adversary of threshold concepts model. Rowbottom (2007) challenged the idea that threshold concepts were not identifiable and there is a lack of consensus among educators as to what threshold concepts are. Firstly, the author expanded upon the weakness of Land and Meyer’s definition in that they stated that threshold concepts are “likely” and “possibly”. Therefore, this infers a lack of empirical evidence. Secondly, Rowbottom maintained that the dominant cognitive science definition of a concept (mental representations, categorizers etc) is still subject to debate among researchers. Rowbottom (2007) also contended that the idea of threshold concepts presumes a non-conceptual world (as in liminality) and this, so far, is unproven. Lastly, he reasoned that all concepts, once learned, are integrative and transformative and significant shifts in thinking need to be defined and measurable.

2.14 A Case for threshold concepts in cell biology

Whether concepts are functional categorizers or threshold in nature, there appears to be evidence to suggest that examining students’ understandings is critical – especially at the first year level. A deeper examination of what could be threshold concepts and ways of crossing liminal boundaries could inform the discipline and be useful to biology educators. What remains to be examined in this study is whether a specific type of concept exists; do some concepts require students to cross a conceptual threshold; and if an emerging framework can result. Using Ross and Taylor's (2009) examples of troublesome knowledge (scale, dynamics, genetics and energy), a study in first year cell biology at the University of British Columbia can be useful to educators.

3 Methodology

3.1 Introduction

There is a lack of understanding of how conceptually difficult content is processed by students in first year biology courses. Much of the research reports that threshold concepts can be applied in multi-disciplinary frameworks from the sciences to humanities (Lucas and Mladenovic, 2007). By drawing on Land and Meyer's (2003) operational definition for threshold concepts, the purpose of this study is to investigate threshold concepts and their potential for high levels of student engagement in a first year cell biology course at University of British Columbia in the faculty of Science.

This study used a mixed methods approach to examine threshold concepts and transformative learning experiences in a cell biology course. I will show how data collected included qualitative feedback from students and cell biology educators to determine the existence of threshold concepts in this cell biology course. I will also show how quantitative (survey instrument) and qualitative (focus group interviews) data was collected to assess and interpret the learning experiences of students in the course.

3.2 Design of the study

3.2.1 Description

Biology 112 at U.B.C is a first year biology course on single cell organisms and is titled "unicellular life". The course is described in the U.B.C. university calendar as "The principles of cellular and molecular biology using mainly bacterial examples. Cellular processes, evolution and the impact of microbial life on the environment." (UBC calendar). According to previous studies of threshold concepts in biology, Ross and Taylor (2009) stated that troublesome or difficult concepts in biology include cellular metabolic processes. The researchers asserted that threshold concepts can be examined in particular areas such as scale, dynamics (e.g. water movement), genetics and energy generation. The biology 112 course offered in winter session 2011 at U.B.C. included three areas of content; cell structure and function, genetics and metabolism which overlap with the four conceptual areas described above by Ross and Taylor.

This study used a mixed methods approach to examine "To what extent do threshold concepts exist in a first year cell biology course?" and "To what extent can threshold concepts engage students in transformative learning experiences in a first year cell biology course?". Qualitative and quantitative data included student written feedback, instructor peer reviewers, a survey instrument and focus group interviews of 25 students from the course.

3.2.2 Finding threshold concepts (Question 1)

For the first research question "To what extent do threshold concepts exist in a first year cell biology course?", I used student feedback on the course material to analyze and develop a framework for threshold concepts. The resultant framework was further examined by instructor peer reviewers.

The student feedback was part of a weekly course activity where students reflected on areas of content they found difficult. I chose to examine this feedback in depth since the feedback was a good reflection of what students understood about the course content as they were progressing throughout the term. This type of feedback had been used by Biology 112 educators for the past few academic years to gauge student understanding. Also, previous research on threshold concepts in biology (Ross et al, 2009) used a similar approach.

On average, 680 students of 870 students would provide a response to a question asking what they found difficult to understand in the material and why. A random sample of 10% was chosen to examine in depth and since students completed the feedback, on-line (using Learning

Management System, WebCT VISTA) the data was easily obtainable, randomized and anonymous. As I was searching for areas that represented difficult concepts, the responses from this feedback was examined for reoccurring themes and used to develop a framework for threshold concepts. The resultant framework was then presented to instructor peer reviewers to substantiate the presence of threshold concepts in the course. The peer reviewers provided feedback on what they believe to be particularly difficult concepts and those that represented threshold concepts.

3.2.3 Examining the learning experience (Question 2)

In the second part of the study, focus groups were used to examine the student experience at the end of the term. Twenty students from the course participated in focus groups interviews. These participants first completed a course engagement survey and participated in an activity and discussion that required them to identify concepts they found difficult.

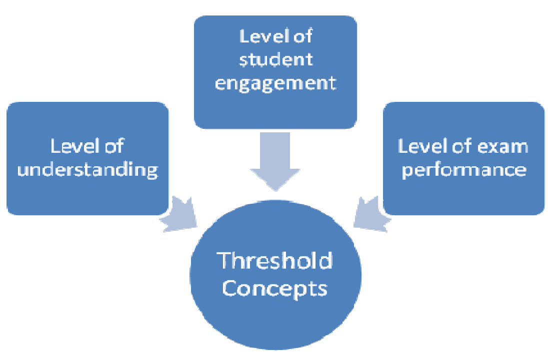
To measure engagement in the course, I chose the Student Course Engagement Questionnaire by Handelsman et al (2005) (Appendix B). I chose this validated instrument because it focused on what elements would engage a student in a particular course as opposed to something that would measure many aspects of university life. The survey instrument covered many aspects of student behaviors in the course such as measuring skills, emotional, participatory and performance engagement. I also chose the SCEQ since the instrument length was appropriate (27 items) to execute the 1.5 hour time period allotted for the focus group interviews that included the survey, an activity and discussion with the students. The results of the survey were used to suggest what level these students were engaged in their cell biology course and if this could relate to their ability to overcome difficulties in conceptual understanding.

Following the SCEQ, the participants were asked to complete an activity where they ranked course concepts as more or less difficult to understand (i.e. from most difficult to easiest). This part of the activity was designed to establish what areas still represented a struggle for the students since the focus group interviews were completed towards the end of the term. As part of a group discussion, the participants were asked to reflect on why they struggled with the most difficult concepts they identified and what course activities did or did not assist them in their learning. The purpose was to provide an ontological investigation into the student learning experience and whether this can provide insight as to whether transformative learning experiences existed.

3.2.4 Exam performance and mastery

The last piece of information that was important to assess whether transformative learning experiences occurred was to examine the exam scores for focus group students after the term had ended. However, exam performances alone are not good indicators as all exams in this course were multiple choice formats and do not elucidate students thinking processes. Therefore, assessing the mastery of a threshold concept in this study was based on three pieces of data; focus groups discussions on the concepts, course engagement levels and exam scores (Figure 3.1, Factors that determine mastery of threshold concepts).

Figure 3.1 Factors that determine mastery of threshold concepts.



3.3 Data collection

3.3.1 Can threshold concepts exist?

To address question 1 of this study “To what extent do threshold concepts exist in a first year cell biology course?” I used students’ struggles as a guide to identify difficult knowledge and characterize threshold concepts within the content of the course as demonstrated by Ross and Taylor (2009). The approach was completed in two stages (Table 3.2, Research Question #1 and Proposed Methodology). The first stage involved summarizing student’s difficulties on understanding concepts that lead to the identification of threshold concepts in the course and the development of a framework for threshold concepts. The second stage used instructor peer reviewers to analyze the framework and suggest key threshold concepts for the course.

3.3.1.1 Identifying student struggles

For the first stage, I collected student written responses and created a list of the most common areas where students struggled (Table 3.2, Sample 1). This data came from feedback that was done weekly throughout the term. For example, in the winter session of 2011, based on weekly pre-reading material, students completed an on-line quiz. Eight quizzes were assigned in the 13-week term. At the end of each quiz, students were asked: “What did you find most difficult (in the readings or assignment) to understand and why?”. On average, over 600 of 870 students would respond.

For each week (from a data set of over 600 responses), I examined 60 random responses (10%) for commonalities and reoccurring themes where students struggled. The 10% sample size was based on previous course experience. Cell biology instructors used this sample size to gauge student understanding and found that it was adequate to represent the students experience and show general themes or trends.

Table 3.2: Research Question #1 and proposed methodology

Research Question	Sample	Analysis	Data Sets
Q1. To what extent do threshold concepts exist in a first year cell biology course?	1. Characterization of Threshold Concepts -identify difficult content: • Student reflections from Biology 112-2011 winter session Term 1. • Instructors reflections	As related to content areas of scale, dynamics, genetics, and energy: • Summarize student responses where difficulties arose. • Analyze instructor's notes/log. • Collate information from students • Identify possible threshold concepts.	Using data sets corresponding over 8 weeks: • 60 responses (Approximately 10% of course responses for all sections; 480 term total) • Proposed framework of threshold concepts.
	2. External Peer Review [Biology 112 educators].	• Identify areas of consensus among peers. • Propose framework for curriculum design; strategies to focus on student learning and problem solving activities. • Feedback from peers.	• 3 peer reviewers • analysis of proposed framework

The reoccurring themes (difficulties in student understandings or misconceptions) was summarized and used to suggest potential threshold concepts that correlate to the topics of scale, dynamics, genetics and energy. I approached the data in the same manner as demonstrated in previous research in biology (Ross and Taylor, 2009), economics (Davies et al, 2007) and physics (Wilson et al, 2010). All these studies used experts and students to identify areas of difficult content and examined student misconceptions in their endeavor to identify threshold concepts.

The data of misconceptions (drawn from the weekly quizzes) were used to identify possible threshold concepts and to develop a proposed framework for threshold concepts. The purpose of developing a framework is to guide decisions on the future curriculum of the course and develop problem solving activities that support the learning environment. The proposed framework could then be used as a tool to analyze current strategies in the course; to address misconceptions in these areas; and develop new strategies and activities that can be easily integrated into the curriculum. For example, a framework or curriculum design tool has shown by previous research to aid in course design and improve student learning (Anderson et al, 2011; Butler et al, 2008; Taylor et al, 2010; Tsay et al 2010).

3.3.1.2 Establishing a consensus for threshold concepts

Threshold concepts were established based on the student data above and placed within a framework. This framework was presented to other cell biology educators to validate their existence and the framework itself (Table 3.1, sample 2). The three peer reviewers consisted of current and former Biology 112 instructors. Given the definition of a threshold concept, and examples in other disciplines, the peer reviewers were asked to examine the framework for threshold concepts. They were then asked to suggest which three concepts, among the framework, would best represent a threshold concept. This approach was also consistent with the previous studies (Davies et al, 2007; Ross et al, 2009; Wilson et al, 2010) where peer reviewers were asked to find consensus among misconceptions and difficult concepts in the discipline and three candidates were examined in detail. The feedback provided from the peer reviewer was then used to establish three concepts that are proposed to be threshold concepts and within a framework.

3.3.2 Threshold concepts and transformative learning

To address question 2, "To what extent can threshold concepts engage students in transformative learning experiences in a first year cell biology course?" I used focus group interviews to obtain feedback from students registered in Biology 112 in September - December, 2011 (Table 3.3, Research Question #2 and Proposed Methodology). In particular, I invited 25 students from all sections of the course to participate in a focus group interview. The interviews required the participants to complete the Student Course Engagement Questionnaire (SCEQ) (Appendix B) for a quantitative assessment of engagement and then complete an activity to identify difficult concepts in the course which also included a discussion (qualitative assessment).

Previous studies in areas of economics, physics and biology all demonstrated that student interviews were necessary to seek out the missing pieces in students' understandings (Ross et al, 2006). Therefore, focus group interviews of a total of 25 students were conducted for an in-depth examination of student understandings and mis-understandings (Appendix A). The purpose was to expose potential areas of conceptual difficulties in the areas previously identified in research question 1 and attempt to identify how students might be suspended in what Meyer and Land (2003) refer to as liminal spaces. This added to the ontological perspective of the study.

Table 3.3: Research Question #2 and proposed methodology

Research Question	Sample	Analysis	Data Sets
Q2. To what extent can threshold concepts engage students in transformative learning experiences in a first year cell biology course?	Invite participation from all sections of 870 students: 1. Students- focus groups • Course engagement survey. • Interview discussion. • Overall exam performance.	Examine: • Students' rankings of most difficult concepts. • Student's understandings of most difficult concepts. • Effectiveness of learning strategies and problem solving activities.	• 7 focus groups of 3- 5 students each [25 students total from all sections]
	2. External Peer Review [Biology 112 educator].	As above plus other insights.	• 1 peer reviewer
	3. Instructor reflections	As above plus insights, future applications	

3.3.2.1 Course engagement questionnaire

The focus group interviews were conducted in groups of three to five students. Seven focus group interviews took place for 25 students. Interviews were conducted in the last two weeks of the term prior to final exams. Since I was the primary study researcher and also a course instructor, a research assistant was present throughout the interview process to ensure no coercion or bias. The research assistant alone administered the survey. Participants were asked to complete a course engagement survey (SCEQ, Handelsman et al, 2005) to measure their levels of engagement in this course (Table 3.2, Sample 1). The surveys were coded and remained anonymous to myself until after the course grades were submitted.

The purpose was to establish to a link between how students are engaged in their learning and whether that learning is transformative by examining what types of behaviors students are engaged in. More specifically, if students demonstrated low levels of engagement, they are less likely to use deep learning approaches and less likely to be able to experience a transformative learning process. Therefore, the instrument was used to quantify what level were students are engaged in their cell biology course, what types of engagement behaviors (surface versus deep approaches) were demonstrated and how this may relate to transformative learning experiences.

3.3.2.2 Focus group interview

Following completion of the SCEQ survey, students were asked as a group to examine course concepts from the framework of threshold concepts developed in Question 1. Both I and the research assistant were present for this stage of the interview. A word processing program (MS Word) and laptop was used by the research assistant to record all comments in the focus group sessions.

The idea or definition of a threshold concept was not discussed with the students. However, all the threshold concepts proposed in the framework were presented on 5” X 8” index cards with a brief description of the concept. Students were first asked to separate the index cards into two categories; concepts they found difficult to grasp/understand and concepts they found easier to grasp/understand. The participants were then asked to rank each category from most difficult to easiest to grasp/understand.

Using the top three most difficult concepts ranked by the group, the participants were asked to discuss and relate their understandings and experiences (Appendix A, Focus group interview questions). They were also asked how specific activities in the course may have helped or hindered their understandings. The interview transcripts were examined for mastery of the proposed threshold concepts as well as the potential for the problem solving activities to transform their understandings.

3.3.2.3 Exam performance

The overall exam grades of the focus group participants were examined to compare if there was any relationship between exam performance, course engagement levels and transformative learning experiences (Appendix E). After the completion of the term and final grades were submitted, the coded focus group participants were evaluated for their total exam performance (Table 3.3). For example, since the threshold concepts identified in the study are also concepts tested on examinations, collectively, the exam performance of focus group participants (midterm and final examinations) was compared to the entire class. The exam data not only served to illustrate at what level these students were able to succeed in the course relative to their classmates but also to see if engagement levels are a good correlation to exam scores. That is, do students with high engagement levels perform better in the course and can this be a predictor of deeper levels of learning i.e. transformative learning experience?

Table 3.4 Total exam performance. All students in the course were evaluated by this exam weighting scheme. Fifteen percent of their grade was allocated to class activities.

Exam	Weighting (%)
Midterm 1	10
Midterm 2	30
Final Examination	45
Total Exam Performance*	Total out of 85 (converted to a percent)

*sample calculation: (7.6/10 + 25/30 + 39/45)/85*100 = 84%

3.4 Participants

The target students for focus groups were students who were registered in Biology 112, term 1 of the winter session of 2011 (September – December 2011). In particular, the target group would be first year students attending a higher education institution for the first time. The selected students for focus group met the following criteria:

- First year students registered in the faculty of Science.
- Are attending a post-secondary institution for the first time.
- Have attended secondary school in British Columbia or Alberta and have the required prerequisite courses from these secondary institutions of biology 11 and chemistry 12.
- Are planning on continuing the life sciences disciplines (e.g. biology, microbiology, zoology, botany etc).

At the end of the term (10 weeks into the 13 week term) , students in all three sections of Biology 112 at the University of British Columbia were invited to participate in the study. Students were pre-screened by the research assistant and twenty five students that fit the criteria above were chosen to for the focus groups. Each focus group consisted of three to five students. A total of seven focus groups interviews were conducted.

3.5 Analysis

3.5.1 Finding threshold concepts

The first part of the study involved looking for difficult concepts in the course that could be threshold concepts. This is where the weekly student feedback ("What did you find most difficult (in the readings or assignment) to understand and why?") was used to examine common areas of conceptual difficulty. For each week (total of 8 weeks in a 13 week term), 60 responses were assessed (480 responses in total). The most common responses or student “difficulties” for each week were short-listed. Depending on the content covered in any one week in the course, some weeks consisted of only a short-list of a single area of difficulty content whereas other weeks may have up to three difficult content areas.

Each reported difficult content area was then translated into a specific course concept. The course concept was then evaluated using the definition of a threshold concept (transformative, troublesome (difficult), irreversible, integrative and bounded). Sixteen concepts were chosen to represent possible threshold concepts. The threshold concepts were then organized into categories to create a framework. The organization of the sixteen threshold concepts was based on the order that the content was presented in the course and the relatedness of the threshold concepts to each other. The framework was also examined for any relationships to previous studies in biology (Ross et al, 2005).

3.5.2 Peer review of a framework

The framework was presented to three instructor peer reviewers for discussion. The reviewers were explained the definition of a threshold concept and provided with examples defined from other disciplines. The peer reviewers were asked to examine the framework and discuss the concepts in the framework as possible threshold concepts. Finally, peer reviewers were asked to suggest three concepts in the framework that best represented a threshold concept. Their responses, in addition to my own interpretation, were examined to determine if the framework was a good representation of threshold concepts in cell biology.

3.5.3 Student engagement survey

The twenty five focus group participants completed the Student Course Engagement Questionnaire (Appendix B). Each completed survey was coded to maintain the anonymity of the student until after the course was over. The results of the instrument were examined by using quantitative data analysis. The questionnaire focused on five components to measure course engagement; extent of engagement based on behaviors; self-reported level of course engagement; self-reported engagement as compared to other courses; belief in learning theory; and goal orientation. This study focused on the results of the first three components to determine the overall level of course engagement by using the average scores of each category.

In particular, the first component, extent of engagement based on behaviors, was further evaluated by four factor; skills engagement, emotional engagement, participation and interaction engagement and performance engagement (as suggested by Handelsman et al, 2005). The analysis using the average scores of these four factors was found to be most useful in assessing what types of engagement behaviors and attitudes these students were exhibiting or tended towards. The average scores of these engagement behaviors was used to suggest areas where focus group participants may use deep or surface learning approaches to learning (Handelsman et al, 2005). For example, high scores in the areas of skills engagement suggest surface approaches to learning whereas high emotional engagement scores suggest deeper levels. This can be examined more closely by comparing the types of questions in the survey in each category. Differences in average scores for component I factors were compared by using a standard t-test (Appendix D).

3.5.4 Focus group discussions

The focus group interview discussions were particularly useful in providing insight as to what students found most difficult in the course using the concepts proposed in the framework (Appendix A). Although the students were aware of the name of the study ("An investigation of student learning using threshold concepts in a first year biology course"), the notion of a threshold concept was not discussed. The purpose was to establish the participants evaluation of their own struggles in learning the concepts presented to them. The analysis focused on the top three concepts each focus group chose as their most difficult concept. The discussion that ensued was analyzed for:

- What elements of the concept that represented a difficulty or struggle.
- Areas which might represent liminal states (suspended in conceptual stasis).
- Class activities that either assisted or impeded their understanding.
- What other kinds of things can assist them in their learning.

3.5.5 Course exam averages

Overall exam averages for focus group participants and all students in the course were calculated after the term had ended and course grades were submitted. The purpose was to compare how the focus group participants performed in the course as compared to the overall class average. Since not all students in the course were examined for levels of course engagement or conceptual difficulty, it was necessary to determine if the focus group participants could represent the overall class. This would establish either a baseline or maximum for the course. For example, when assessing engagement levels, if overall course averages were lower than focus group participants this would indicate overall the students in the course are most likely less engaged than focus groups. Similarly, lower overall course averages than focus groups could be interpreted as less conceptual understanding among all students in the course.

3.6 Summary

Threshold concepts in the course were identified using educators and students' feedback. A framework was developed and the impact of threshold concepts on student learning was examined. Data was collected from a course engagement survey, focus group interview discussions, and exam performance. To establish mastery of the threshold concept and whether a transformative learning experience occurred, interpretation of study data involved analyzing students' understandings of threshold concepts in the course, assessing levels and types of course engagement and academic abilities as discussed in Chapter 4.

Using the framework for threshold concepts and student interviews, this study can suggest how threshold concepts can be used to view curriculum design. This study will examine and recommend areas that may require further examination as well as critical points where student learning can be improved in Chapter 5.

4 Findings

4.1 Introduction

The student learning experience was examined using the definition of a threshold concept as a way of viewing difficult concepts in a first year cell biology course. The notion of a threshold concept is relatively new area of research and there was a need to identify concepts in cell biology as threshold concepts. Therefore, the first part of this study involved identifying possible threshold concepts by using feedback from students and educators in cell biology to develop a framework for first year cell biology courses. Threshold concepts are defined by Meyer and Land (2003) as transformative, troublesome (difficult), irreversible, integrative and bounded. In addition, to master a threshold concept is analogous to crossing a conceptual threshold or boundary into new areas of understandings. Therefore, it was necessary to consider only concepts that can be defined as a threshold concept in this study. The resulting 16 threshold concepts identified from the course were found to fit into the categories of scale, dynamics, genetics and energy generation and from this, a framework was generated. From this framework, educators in cell biology were then asked to focus on three areas that best fit into the threshold concept model.

The framework for threshold concepts in biology was then further examined by obtaining feedback from students currently registered in the course via focus group interviews. The interviews were conducted in the last two weeks of the term in order to best ascertain experiential learning in the course. Since this study examined the potential for threshold concepts to provide a transformative learning experience, focus group participants were surveyed for levels of course engagement using a validated questionnaire. In addition, these students were asked to participate in an activity that involved using the framework mentioned above and identifying their own areas of difficulty. The purpose was to have students' independently validate the chosen threshold concepts from the framework.

4.2 Data analysis and examples

4.2.1 Can threshold concepts exist in a first year cell biology course?

To address the research question "To what extent do threshold concepts exist in a first year cell biology course?", I will explore how difficult concepts from the course were used to develop a framework for identifying threshold concepts using student and instructor peer review feedback.

Since threshold concepts represent core concepts that may be particularly difficult to master, the first step to identify a threshold concepts in a first year cell biology course was to identify possible difficult concepts in the course. These types of concepts were then distinguished from those that are integral to a course (yet may not be a threshold concept) versus areas of misconceptions and difficulty which are more likely to fall into the definition of a threshold concept. Therefore, particularly difficult concepts were ascertained by obtaining feedback from students currently in the course, feedback from instructors in the course (current and past) and my own interpretations as the study researcher and an instructor in the course.

4.2.1.1 Student feedback

It was important to gain insight as to what current students (fall term, 2011) found difficult about the material as they were exposed and taught the material. More importantly, the timing of the student feedback collected was such that it was immediate, based on current material and a true reflection of students' interpretations without bias from instructors or exam performance.

To obtain this type of student feedback, students were invited to provide their opinion on what they found difficult about the weekly readings and topics. This is a regular part of course assessment and feedback. For example, throughout the term, students were required to complete on-line pre-class quizzes for participation marks (using the learning management system, webCT VISTA). At the end of each quiz, students were asked the question "what did you find most difficult to understand and why?". Throughout a 13 week term at U.B.C., students completed eight quizzes and the question above was posed at the end of each on-line quiz. A minimum of 70% of the student body (i.e. at least 600 of 870 students) voluntarily responded to the question.

Table 4.1: Sample of student responses "What did you find most difficult to understand and why?" and the relevant course concept.

Quiz Week	Response	Concept Category
3	*"understanding the chemical structure of the phospholipid bilayer, because there were many different types of bonds to understand."*	**Polarity of Molecules**
7	*"to relate and find the interactions of the enormous amount of information about transcription and translation was the most difficult part of the pre-reading assignment."*	**Structure and Function of Nucleic Acids**
11	*"reviewing oxidation and reduction reactions."*	**Oxidation Reduction ("redox") Reactions**

Since there were hundreds of responses to the question above, a random 10% of the responses (60 responses) were chosen to examine in depth. It has been previously determined by instructors that assessing 10% of student responses was adequate to represent the class. The areas of difficulty reported by these students were then categorized into concept themes (Table 4.1). For example, if a student would report that they found the "*different types of bonds*" as challenging; this was categorized into the concept of "*polarity of molecules*". Re-occurring themes that comprised the majority of responses would then be considered to represent the key problem areas for that week. Although eight quizzes were examined, sixteen areas were identified due to multiple emerging difficult concepts in any one week.

4.2.1.2 Sixteen concepts for a framework

According to previous studies of threshold concepts in biology, Ross and Taylor (2009) suggested a framework for threshold concepts that can be categorized into the areas of scale, dynamics, genetics and energy generation. The 16 difficult concepts derived from student feedback were found to fit into this framework. Using these 16 course concepts, the model of Ross and Taylor (2009) and the definition of a threshold concept (Land and Meyer, 2005), a cell biology framework was established (Table 4.2). The resultant framework also adequately reflects the diversity of the topics covered in the course curriculum.

Table 4.2: Framework for threshold concepts in cell biology.

Scale	**Dynamics**
Cell Size	Polarity of Molecules
Cells are Microscopic	Hydrophobic Effect
Eukaryotic and Prokaryotic Cells	Transport of Molecules In and Out of a Cell
	Protein Structure
	Enzymes as Catalysts
Genetics	**Energy Generation**
Structure and Function of Nucleic Acids	Oxidation Reduction (“redox”) Reactions
Directionality of DNA	Energetic Coupling
DNA Promoters	Cellular Respiration
Transcriptional Control of Gene Expression	
DNA synthesis	

The 16 difficult concepts as reported by students were found to easily fit into Ross and Taylor’s (2009) categories with the exception of two – “protein structure” and “enzymes as catalysts”. Upon further consideration, I found that they should be represented in the area of “dynamics” since mastering these two concepts is dependent on mastering three other concepts in this category (“polarity”, “hydrophobic effect” and “transport”).

4.2.1.3 “Instructor” peer review feedback

In addition to the student feedback, three peer reviewers were consulted and asked to identify difficult concepts in the course that may represent a threshold concept. Instructors were provided with a definition of a threshold concept (transformative, troublesome, irreversible, integrative and bounded) and with examples from other disciplines such as the most clearly defined example “thermodynamics” in physics. The examples were drawn from disciplines outside of biology so as not to influence the peer reviewers as to the interpretation of threshold concepts in cell biology. The instructors were also given the list of the 16 concepts identified by students - however not in any particular order or within the framework (Table 4.2). Two of the reviewers were current instructors of the course and the third reviewer had taught as recent as May 2011. None of the peer reviewers were familiar with threshold concepts and so did not represent any bias in their ability to consider any of the 16 concepts, a threshold concept. When presented with the definition of a threshold concept, the ability to be transformative and irreversible (unlikely to be forgotten) was emphasized as a key differentiation between concepts that are challenging and those that are threshold concepts.

The peer reviewers decided to choose mainly three concepts that would best represent a threshold concept based on their own experiences (Table 4.3). This is similar to the studies of Akerlind & Wilson, 2010; Davies and Mangan (2005); Ross and Taylor, 2009 where experts in the field narrowed their examples to three or less threshold concepts to examine in detail.

Table 4.3: Peer review rankings of possible threshold concepts in cell biology.

	Peer Reviewer 1	Peer Reviewer 2	Peer Reviewer 3
1	Oxidation Reduction Reactions/ Energetic coupling	Energetic coupling	Oxidation Reduction Reactions/Cellular Respiration
2	Transcriptional Control of Gene Expression	Transcriptional Control of Gene Expression	Hydrophobic Effect
3	Polarity of Molecules	Polarity of Molecules/Enzymes as catalyst	Polarity of Molecules

All peer reviewers, notably, discussed the idea that threshold concepts were embedded and linked to ideas and theories that underlie these concepts. For example, "polarity of molecules" and "enzymes as catalysts" required an understanding of a type of inter-molecular interactions (as in polarity) thus the peer reviewers chose to group these together. While the framework for threshold concepts in biology (Table 4.2) identified these as two distinct threshold concepts, many of these were grouped from the instructor perspective. This is consistent feedback from further studies of Ross and Taylor (2010) that suggested threshold concepts within biology comprise a web of concepts as well as Davies and Mangan (2003) in economics that suggested conceptual categories were overlapping and linked in some form.

4.2.1.4 Study researcher feedback

As the study researcher and also a course instructor, I used the framework in Table 4.2 to identify which concepts I was most confident in defining as a threshold concept. Table 4.4 represents three such threshold concepts and fits into the framework as in Table 4.2.

Table 4.4: Three threshold concepts ascertained by study researcher

Rank	Study Researcher
1	Energetic coupling
2	Oxidation Reduction Reactions
3	Directionality of DNA

In keeping with the peer review feedback, I chose three areas that best represented the most difficult areas of the course and by definition are threshold concepts. All three areas overlapped with at least one of the three peer reviewers. For example, "oxidation reduction reactions" and "energetic coupling" were also identified by two of the three peer reviewers. This suggests that some degree of consensus exists among the course instructors. The exception was "hydrophobic effect" that was deemed to be an important threshold concept by only one reviewer. Since not all difficult concepts are threshold concepts (that is, may not be transformative in nature), further analysis with more peer reviewers would be needed to ascertain whether "hydrophobic effect" and "directionality of DNA" are represented appropriately as a threshold concept.

It is important to note that these proposed threshold concepts (represented by those with expertise in the field of cell biology) fell into only two the four categories from the framework such as "genetics" and "energy generation" (Table 4.2). Overall, the framework was found to be useful in categorizing threshold concepts in cell biology although in this particular study there was a greater emphasis on 50% of the framework presented. A deeper analysis and evidence of these threshold concepts needed to be explored. Subsequently, student feedback in the focus group interviews were useful in providing evidence, that to students, there was a greater emphasis in the last half of the course material represented by the lower half of the framework for threshold concepts in cell biology (Table 4.2).

4.2.2 Threshold concepts and engaging learning

To address the question "To what extent can threshold concepts engage students in transformative learning experiences in a first year cell biology course?", student focus group interviews were conducted where students were asked to complete a course engagement questionnaire, participate in an activity to identify difficult concepts and reflect on class related activities throughout the term (Appendix A).

4.2.2.1 Relating student engagement to transformative experiences

As threshold concepts are thought to provide transformative learning experiences and can shift one's thinking, it was important to measure the students' level of engagement in the course. As the general literature suggests, engaged students are better learners (Floyd et al, 2009) so it stands to reason that the higher levels of engagement in a course can lead to the greater transformative processes. Conversely, students with low levels of engagement would unlikely have a transformative learning experience as they are not thinking about the material in depth.

I chose the Student Course Engagement Questionnaire (Appendix B) developed by researchers Handelsman, Briggs, Sullivan and Towler (2005) aimed at measuring engagement in courses at in the lower level. They defined their 27- item questionnaire as focused in the "micro" level- "what happens in and immediately surrounding the class" (Handelsman et al, 2005). I believe this best reflected the nature of students in our course and the learning environment. Ultimately, the SCEQ could measure factors associated with directly with a course. Many other engagement surveys aimed at evaluating the effectiveness of programs and the overall perceptions of students at university which would not be appropriate for this study.

Students from all sections of the biology 112 course in the fall term of 2011 were invited to participate in a 90 minute focus group interview that explored concepts from the course (Appendix A). The interview was conducted in the last two weeks of the term, prior to the final examination period. Twenty five students organized in seven focus groups were selected (three to five students per focus group). The 25 students were evenly distributed from each section (9, 8, 8 from section 101,102, and 103 respectively) and represented students who were attending a post-secondary institution for the first time. Eighty percent of these participants were females and twenty percent were males. This represented a slightly higher gender distribution than the course itself with 60% females and 40% males registered.

4.2.2.2 Measuring levels of course engagement

At the start of the group interview, the focus group participants were asked to complete the validated, 27- item SCEQ (Appendix B). Each participant individually completed the questionnaire prior to the commencement of the focus group interview. The SCEQ results were interpreted by summarizing: the extent of engagement on behaviors; self-reported level of course engagement, self-reported engagement as compared to other classes; belief in learning theory and goal orientation (Table 4.5). First, I will discuss the results of this questionnaire and show that these students, although moderately engaged in the course, failed to show high levels of engagement. The level of engagement will discussed further as a way to interpret focus group interviews and suggest the possibility of a transformative learning experience.

Table 4.5: Summary of results of the student course engagement questionnaire (SCEQ)

Component	Description	Interpretation
I	Extent of engagement based on behaviors.	Engagement Level 65% (±11)
II	Self-reported level of course engagement.	Engagement Level 64% (±14)
III	Self-reported engagement level as compared to other classes.	Engagement Level 57% (±24)
IV	Belief in learning theory – can intelligence be changed?	Agreement in extent that intelligence cannot be changed = 75%
V	Goal orientation – choose between good grade v.s. being challenged	80% reported good grades 20% reported being challenged

4.2.2.3 Component I – Extent of engagement based on behaviors

The extent of engagement based on behaviors was examined using items 1 - 23 of the 27 items and a 5- point likert scale (Table 4.5, component I). The overall average score on the 23 question items was 3.23 ±0.66 (Appendix D). This suggests that students were engaged in their learning and in the course material to some degree but not at high levels. This portion of the SCEQ can then be further discriminated into four factors such as “skills”, “emotional engagement”, “participation and interaction” and “performance”. These factors can be used to further elaborate on the types of behaviors, thoughts and feelings the students are producing in the course (Table 4.6).

For example, the first category “skills” represents students’ engagement through practicing skills as compared to the second factor “emotional” engagement through emotional involvement with the course material. Participants in the focus groups appeared to be more engaged in applying skills (e.g. being organized, taking notes in class) as opposed to being emotional engaged in the material (e.g. finding ways to make the course material interesting).

Table 4.6: Factors associated with the extent of engagement based on behaviors.

Factor*	**Mean Ratings likert scale 1 -5 (SD)**	**Corresponding Test Items**
Skills Engagement	3.59 (± 0.51)	1 - 9
Emotional	2.92 (± 0.33)	10 -14
Participation and Interaction	2.80 (± 0.86)	15- 20
Performance	3.55 (± 0.16)	21 - 23

**p<0.05 for all factor comparisons except skills v.s. performance, emotional v.s. participation (Appendix D)*

Alternatively, factors such as “participation and interaction” represented student engagement through participation in class and interaction with instructor. This appeared to be lower than their performance engagement where students rated test items “raising my hand in class” and “going to the professors office to review assignments and tests or ask questions” as the least characteristic of them. Lastly, the factor of “performance” represented engagement through levels of performance such as “doing well on tests”. This would indicate a tendency for students to be more performance or goal oriented rather than trying to become more involved in subject areas to master learning theory. The performance test items collectively had higher average ratings than in participation and interaction engagement (Table 4.6).

Overall, the SCEQ results suggested that focus group students were more oriented towards replicating behaviors that are associated with good grades such as doing homework problems, doing well on tests. Post-term analysis of these students’ grades showed that focus group participants achieved almost 8% higher average on weighted exam scores from the rest of the class (Appendix E). As this seems to represent a group of students who performed better in the course as compared to the class, it is not surprising that their self-reported behaviors were skills and performance oriented. These students may place a higher value on these behaviors because it has produced results for them in prior experiences. As these were first year students attending university for the first time, it was not surprising they relied on familiar study skills. Conversely, factors such as emotional and participation/interaction were rated lower because perhaps first year students are not convinced that these are important factors in learning. Therefore, it is prudent for educators to examine how learning in the course is modeled such that we demonstrate to students that emotional involvement and participation can assure as much success as applying a subset of study skills.

4.2.2.4 Students' self-reported engagement levels

It is clear from the data shown in Table 4.5, component I, the SCEQ rated student behaviors, thoughts and feelings on average to have an engagement level of 65% (±11). This was consistent to student self-reported engagement levels (Table 4.5, component II) in the course which was similar (64% ±14). This gives credence to the ability of the SCEQ to accurately reflect the students' interpretation of their own engagement. When asked how engaged students felt relative to other courses (Table 4.5, component III), it appeared overall that students felt less engaged in their cell biology course (57% ± 24) yet had a greater variability in the responses. For example, 15 of the 25 responses rated themselves as being at least 74% or greater engaged in this cell biology as compared to other courses. The 10 remaining students mostly rated themselves as only 32% engaged relative to their other courses in the semester. This seems to indicate a distinct split in make-up of these focus groups students however their average responses for components I and II as well as their course exam averages were consistent with the rest of the group. As the study researcher, I would conclude that students are able to accurately self-report their engagement without influence. Since focus group students, overall, had higher performance levels than the entire class (i.e. 8% higher exam averages), it would lead us to believe that students can still achieve good grades even if they are less likely to be highly engaged. This is perhaps reflective of their skill and performance driven perception of success or mastery of a subject.

4.2.2.5 Learning theory and goal orientation

The last two test items on the SCEQ, “belief in learning theory” and “goal orientation” (Table 4.5, components IV and V) showed that 75% of students believe that intelligence cannot be changed and 80% of students would chose a good grade over being challenged. These results further substantiate that these students are skills and performance oriented as shown in the measurement of the extent of engagement (Table 4.5, component I). Consistent with their responses in this part of the engagement survey, students believe that non-emotional behaviors are equated to success in a course rather than a process of learning. If students believe that intelligence can be changed, then perhaps they would be more likely to spend more time involved in activities that promote emotional and participatory engagement.

4.2.3 Focus group discussions - student perspectives

The central part of the focus group interviews asked participants to reflect on difficult concepts in the course and the related lecture activities they participated in throughout the term. The purpose of interview was to gain three main areas of information from students: How would focus group participants rank the most difficult course concepts using the 16 concepts presented to them? Discussing their most difficult concepts, what elements of each concept were found to be difficult to master? What activities in the course aided in their understanding of these concepts?

I then used this feedback to ascertain which of the concepts in the framework would best represent a threshold concept and if these difficult concepts were consistent with the results by peer reviewers in section 4.2.1 and represented in the framework of threshold concepts (Table 4.2 "Framework for threshold concepts in cell biology").

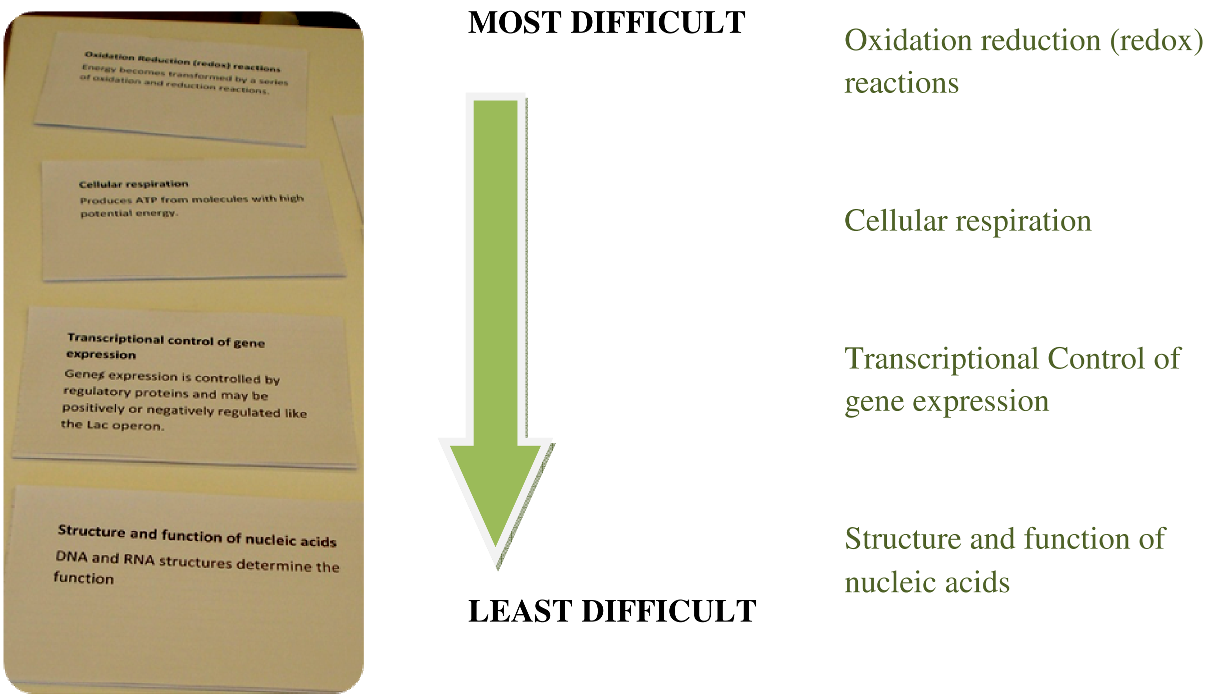
The first part of the process was to present the 16 concepts from the framework of threshold concepts and ask students to rank these into areas of content that was easily understood versus those that were more difficult (Appendix A). Each concept from the framework in Table 4.2 was presented on a 5" X 8" index card and included a brief description of the concept. For example, "transcriptional control of gene expression" included the statement "*Gene expression is controlled by regulatory proteins and may be positively or negatively regulated like the Lac operon.".* This description was useful to avoid any misinterpretations by students. Verbal guidance, however, was also sometimes used if it was perceived students were off-track. The index cards were useful for this task, since they could be easily moved around on a table as the focus group was reflecting on their choices (Figure 4.8).

Although there were variations in the rankings of the 16 concepts between the seven focus groups (Appendix C) the following three concepts were consistently arranged as the top three "most difficult" categories (Table 4.7). These top ranked concepts will be discussed in more detail.

Table 4.7: Top three most difficult concepts ranked by focus groups

Rank	Concept	Focus Group
1	Cellular Respiration	F2, F3, F4, F5, F6, F7
2	Transcriptional Control of Gene Expression	F1, F2, F5, F6, F7
3	Oxidation Reduction Reactions	F1, F2, F3, F6

Figure 4.8: Focus group 6 “Most difficult to grasp/understand” category. Students ranked concept cards into orders of difficulty.



4.2.3.1 What makes a concept difficult?

Focus group participants were asked to discuss why they considered the categorized difficult concepts in “Top three most difficult concepts ranked by focus groups” (Table 4.7) as most difficult. Specific themes emerged on relating the difficulty of any of the three concepts such a struggling with the readings; struggling to understand the vocabulary; linking concepts; and recognizing the important elements.

For example, for “cellular respiration” and “transcriptional control of gene expression” students reported the readings as difficult and struggled to understand the ideas as they read through the material. The students felt that the material covered many steps that were presented in both the readings and lectures and they had difficulty seeing the big picture. In other instances, the examples used to illustrate similarities and differences presented a struggle:

“Confusing because we have different examples and have to apply to different situations”

Yet it is critical for university level biology courses to use various examples to show the diversity of life. To be integrated within the discipline means dispelling the myths that there is only one process that exists. This can be confusing to students with only secondary school education that was taught one method, system or example.

Several pointed out that the new vocabulary hindered their learning process. This observation is consistent in Perkins (1999) research where the learner must engage in discursive practices to allow for a new identity which is required to cross the conceptual gateway in threshold concepts (Land & Meyer, 2003). For students to be able to converse within a discipline, the new language and vocabulary must be first understood and accepted. These students struggled with the new terms and language presented:

“There are so many new words that we don’t learn in high school.”

“I know the main point, but to explain in details and use the right vocabulary is harder.”

Educators may assume that terms are not new or conversely, understood implicitly. We may be overlooking the importance of mastering terminology and therefore, should encourage students to practice a discourse and develop a dialogue with each other.

Additionally, several students recognized that “cellular respiration” and “oxidation reduction (redox) reactions” were linked concepts but were not confident in describing how:

“*I know redox and cellular respiration fit together, but I don’t really know how they do*.”

Since a grasp of “oxidation reduction reactions” (redox) requires a solid understanding of chemistry, participants commented on either finding the concept easier or more difficult as compared to their chemistry class. The students went on to discuss how chemistry is viewed differently in biology and were confused as to how to master the same process in both disciplines. I would suggest that this is one area where students may be suspended in a liminal state (Land et al, 2003) waiting to cross the conceptual threshold. To surpass this state of unknowing, students need to be clear as to how to apply the same principle in both disciplines. Educators can design activities such that students can be led through the problem from the perspective of both the chemist and the biologist.

Lastly, first year students who are attending university for the first time, often cannot discern what is important and why. When describing "cellular respiration", one student stated:

> "*My problem is I don't know what I don't know. I think I know the surface, but I don't know how to go in depth. We are so used to studying the basics and not having to go deeper. I don't know how to go deeper with these subjects.*"

This exemplifies not only the struggles these students are facing in their learning experiences but their own recognition that deep learning processes are necessary. As educators, we need to show them a path to understanding by providing a direction to "dig" below the surface when presented with challenging ideas and processes. If we fail to provide this guidance, we will be losing the potential for an emotional engagement between the students and the material.

4.2.3.2 Do learning activities' aid students in transformative experiences?

When students were asked to recall any learning activities that were related to the threshold concepts presented, many of the students reported the lecture activities as being helpful to their understanding. For "transcriptional control" students found the in-class multiple choice questions (called clicker questions) as helpful and reported drawing pictures or visualizing the process provided additional understanding. In contrast, "cellular respiration" and "oxidation reduction reactions”, students found both the in-class activity and the video animation helpful. In particular, many of the focus group participants found working on the activities in groups allowed them to discuss the material with their peers.

> *I learn a lot during the activities, it was really helpful. More than just listening in the lectures because I have to think through it for myself.*

On the other hand, participants commented that time was often a deterrent to learning.

> *“Its hard because we were just exposed to it, it takes a while to get comfortable with the subject”*

Since students can be suspended in a state of conceptual stasis as described by Kinchin (2010), they require time to process the material. However, university courses and timetables often do not include time for merely “thinking”. Students who become “comfortable” faster, or cross conceptual boundaries more quickly are more likely to excel in higher education. We can ask if this is an indicator of intelligence or where prior experiences can expedite conceptual understanding. For students who felt they mastered the concept, they spent a lot of time reviewing examples, re-reading the material “*word for word*” until they reached an “*epiphany*”.

4.2.3.3 Suggestions from focus group participants

In addition to the discussion of the three most difficult concepts, the participants offered suggestions as to how to improve the course. For example, these students felt that they would like to see more sample problems with a sample solutions as well as more general practice questions. This way of thinking is consistent with the “skills engagement” on the SCEQ. Students place a great emphasis on the idea that solving more problems will lead to greater learning. While this practice is often used in disciplines such as mathematics and physics, enhancing learning in biology is not associated with this type of ritual practice. Problem solving can be one way where students can engage themselves in the material however; the solutions in biology often do not involve a set of steps that can be applied in every situation. An interesting point related within the discussion of problem solving was the recurring theme of time allotted in class to just "think". Students would like more time to "*sort out their thoughts*". Although in Biology 112, in-class activities are often allocated a full 50 minutes of the lecture time, it is possible that we do not leave enough time for "thinking" during these activities. As educators we are always trying to find a balance between keeping students busy and allowing time for processing the material.

4.2.3.4 Useful learning strategies in Biology 112

Biology 112 is a team taught course and all sections utilize the same content and learning activities. Therefore, they should not be any discrepancies among course sections and the ability to capture engagement and participation. There were three type of learning strategies that were designed to help students practice problem solving, group work and use discursive language; clicker questions, investigation activities and half-sheet activities. All these activities were done in class and required students to engage with their peers in finding consensus for a best answer.

For example, clicker questions are used consistently throughout the term where students use remote control devices to respond to multiple choice questions. Although students individually and anonymously respond to the question, they are first required to discuss the question with their peers. This activity was found to be useful to both instructors and students as the questions were often designed keeping misconceptions in mind. Many of the students in the focus groups mentioned clicker questions as an effective way to learn the material and understand the more difficult concepts.

To stimulate group work and discussions, students completed activities in groups of 2-3 called "Investigation" activities. An entire lecture would be devoted to this type of activity that were designed to be more exploratory but based on the core concepts. There were six activities scheduled throughout the term such that students would spend one lecture out of six on an investigation activity. One of these activities related to the threshold concepts of “transcriptional control of gene expression”. A second activity completed towards the end of the term explored both “oxidation reduction reactions” and “energy generation”. Almost all the focus group participants discussed the usefulness of these activities but some more than others. The focus group found these activities useful and therefore worthy of assisting in the conceptual understanding.

The third type of in-class activity called “half-sheets” were found to be the least useful to guide students in their conceptual understanding and problem solving skills. Students would be provided with blank half-sheets of paper (an 8.5” X 11” paper cut in half). A question would be posed in class; students would discuss with their peers and submit their papers. This type of activity was designed to be short and break up the lecture material however often took longer than expected. None of the focus group participants mentioned the “half-sheets” as useful activities.

In summary, both clicker questions and investigation activities were found to be useful to address key areas as well as threshold concepts in the course. Based on this study, I would recommend that both clicker questions and investigation activities are designed specifically with threshold concepts in mind.

4.2.3.5 Evidence of transformative learning experiences

It was not clear at the time of the study whether students had truly mastered the threshold concepts proposed in the framework. Some focus group participants offered comments that suggested they understood any one of the three threshold concepts examined (Table 4.8).

However, when asked how confident they would be in explaining this concept to another student, most responded as not very confident. Since the interviews took place prior to the final exam, several participants remarked that they may feel more confident after they had studied the material in detail in preparation for the final exam. Therefore, a follow-up study would be recommended to conclude if indeed a transformative learning experience has taken place.

4.3 Key findings

For a first year cell biology course, I was able to develop a framework from which core concepts may distinguish as threshold concepts and can be categorized into four key areas in the discipline; scale, dynamics, genetics and energy generation. Based on the framework, three particular areas were identified by instructor peer reviewers as a threshold concept; “energetic coupling/oxidation reduction reactions”, “transcriptional control of gene expression” and “polarity of molecules”. These fell into the key areas of genetics and energy generation and represented 50% of the framework. Using focus group interviews, student feedback was able to corroborate that “energetic coupling” and “oxidation reduction reactions” and “transcriptional control of gene expression” represent areas that may be troublesome for students. These concepts are linked and appear to hold students in a liminal state that needs to be surpassed for conceptual understanding. A third threshold concept was distinguished by instructor peer reviewers that differed from the student group - “polarity of molecules”. Focus group participants ranked this concept as less difficult and this was not discussed further in the context of the study.

Since threshold concepts involve a transformative learning experience, the level of student engagement in the material is a critical to their mastery of any of the threshold concepts identified. Based on focus group participants, the level of engagement in their cell biology course was determined to be moderate (65% engagement levels) but not achieved at a high level. In particular, students lacked an emotional engagement in the material and were more focused on applying a set of study skills that was performance driven. This group demonstrated lower levels of participation and interaction with the material although their exam scores were 8% higher than the class average. It would be expected that students with higher grades would be more participatory than their peers and therefore, it can be concluded that the focus groups would represent average or higher levels of engagement as compared to the rest of the class.

Lastly, participants in focus group interviews were able to illuminate the challenging aspects of these threshold concepts. In particular, students found that the complexity of the readings and lectures made it difficult to see the larger picture. They were also hindered by the language of biology and experienced difficulty linking concepts while discerning what the important elements were and why. It was clear that students recognized the importance of using deeper learning processes however did not know how to navigate their learning to reach this goal. The surface learning approaches they were familiar with were inadequate to allow them to formulate new understandings. Useful learning strategies such as the clicker questions and investigation activities were found to be successful in assisting students in deeper learning processes.

4.4 Conclusion

Threshold concepts are core concepts that provide students with a transformative learning experience and represent a way of transformed thinking and interpreting knowledge (Land & Meyer, 2006). This study investigated the potential for threshold concepts to exist in a first year cell biology course and using a framework on threshold concepts in biology was able to identify threshold concepts that were represented in 50% of the framework. The threshold concepts identified by both educators and students are suspected to be an impediment for the students to pass through liminal states and cross the threshold of conceptually understanding. To improve the student experience in cell biology, it was shown that high levels of engagement particularly in those areas that represent a threshold concept are needed to overcome conceptual stasis and indifference in the learning process. In particular, the threshold concepts identified are integral to the disciplinary understanding and critical to master to continue in biology. Therefore, it is imperative that educators find ways to help students overcome difficulties in understanding discursive language, linking concepts across the disciplines and distinguishing important concepts that are central to biological processes. This can be achieved by engaging students in class using challenging clicker questions and investigation type activities.

5 Conclusions, Implications & Recommendations

5.1 Introduction

Threshold concepts have been described as a model for educators to explore students' understandings of difficult content. This study investigated "To what extent do threshold concepts exist in a first year cell biology course?" and "To what extent can threshold concepts engage students in transformative learning experiences in a first year cell biology course?".

With this study, I was able to develop a framework of threshold concepts that are critical to master within the discipline of life sciences. Therefore, defining threshold concepts in a course can be particularly useful to educators teaching first year life science students. This exploration involving first year cell biology students demonstrated that defining which course concepts that represents threshold concepts and finding consensus among educators can be a difficult task. That which separates a threshold concept from merely challenging course content can be debatable with experts in the field and each threshold concept identified in this study would need to be investigated in-depth.

In addition, using a course engagement questionnaire, the study showed these first year students are only moderately engaged in the material and have a greater focus on previously acquired surface learning skills. They lack the deeper and emotional engagement required to master the threshold concepts in the course. Using an in-depth discussion of threshold concepts within the course, students' struggled to define what was problematic with the content and thus reflects their inability to cross a conceptual threshold (boundary) to greater understanding. Although specific learning strategies such as clicker questions and investigation activities used in this cell biology course was able to target conceptual difficulties and engage students to some degree, more development in this area would be beneficial.

5.2 Discussion and summary

5.2.1 Do threshold concepts exist in cell biology?

The first part of the study investigated if threshold concepts can be identified in a first year cell biology course. Threshold concepts represent difficult content that is also defined as transformative, irreversible, integrative and bounded. Using a first year cell biology course, I was able to create a framework and identify several areas that can represent threshold concepts; specifically within genetics and energy generation. This framework was examined in depth by other educators and experts in cell biology as a peer review process. Feedback from peer reviewers concentrated on two of the four areas of the framework which happens to represent the latter half of the course curriculum. Previous studies have reported that sometimes there was a lack of consensus as to what is defined as a threshold concept among educators and discipline experts. Although some consensus among the cell biology educators existed, there was also a divergence of opinion. After drawing from student feedback in the focus groups, it was evident that students ranked some of the threshold concepts from educators as easier content (e.g. "polarity of molecules"). Hence, these concepts were not investigated further in the scope of this study. However, specific concepts consistently arose between these two groups - "transcriptional control of gene expression", "oxidation reduction reactions" and "cellular respiration" which are all critical concepts to master in the discipline.

The idea of a threshold concept is important to be able to distinguish between concepts that were key concepts or building blocks from those that can shift a learner's perspective and thus provide a transformative learning experience. This shift is often associated with a new identity of the learner including a change in attitudes, values and feelings. The chosen threshold concepts in this study ("cellular respiration", "oxidation reduction reactions" and "transcriptional control of gene expression") do require this shift in perspective and once mastered are irreversible. However, the scope of this investigation was limited to their identification and the issues that arose in the students. At the conclusion of the study, it was not clear if the students had experienced this transformation since the study did not directly explore this further. Students in focus groups also lacked the confidence that they understood the concepts.

5.2.2 Engaging the first year student

First year students require support in learning to overcome preconceived notions of what skills and abilities are necessary to succeed in learning at higher education institutions. There is a gap between what educators and students expect for success. Using a course engagement survey and student participation in a focus group interviews, it can be concluded that these cell biology students were mainly focused on surface areas of learning. For example, this study showed that these students relied upon types of course engagement such as study skills and performance oriented behavior that is often equated to surface learning. Overall the students were moderately engaged in the course but lacked the emotional and participatory engagement required to learn at deeper levels.

This connection is important since in order to master a threshold concept, there is a need to shift students' attitudes, values and feelings. The ability of the learner to formulate a new identity allows them to cross conceptual boundaries into new areas. It was determined that these students were able to acknowledge what concepts represented a conceptual struggle and they were also able to recognize that these concepts were linked. However, at the time of the study, it appeared that student had failed to move through the conceptual threshold. The students did not know what tools could allow them to do this. As they were clearly open and accepting of their struggles, it was evident they were suspended in a liminal state. Focus group participants who were confident that they understood the concept used repetitive techniques (e.g. reading material over and over). This type of application is analogous to applying surface level skills.

To improve course engagement and in particular engagement in threshold concepts, these students must not only be shown the value of developing an emotional connection to the material but shown ways to develop this. It was clear the students valued working in groups and participating in activities but felt they lacked the thinking skills required for mastery.

As educators, we need to develop the curriculum and activities that considers better approaches that address learner difficulties. Although two learning strategies in Biology 112, clicker questions and investigation activities were found to be useful, more development is needed. For example, we need to find ways that engage students emotionally, support and promote participation, allow time for more self-reflection and assist them in crossing the threshold towards newer conceptual challenges. This will subsequently promote the integration of the ideas and theories as well as mastery of discipline-specific content that is a threshold concept.

5.3 Implications

There are several implications that can be drawn from this study from the examination of threshold concepts within a first year cell biology course. First, there exists a framework from which threshold concepts can be identified in cell biology and this can provide educators with a guide as to prepare their curriculum content and be cognizant of areas that represent conceptually difficult content. Threshold concepts do exist in cell biology and the threshold concepts identified in this study are integral to the understanding and mastery of the discipline. Using this knowledge, it is imperative that educators frame their lectures and activities from the expectation that students will struggle with this difficult content and will require time and assistance to cross the conceptual threshold. Drawing on students' previous knowledge, educators in cell biology can use this self-reflection as a tool to encourage a deeper engagement in the content. Once a threshold concept is identified, educators themselves will have a deeper understanding of student struggles and will react accordingly to the needs of the course. Course design could involve excursive and recursive practices (spacing and re-visiting threshold concepts) so as to provide the learner with opportunities to cross the threshold into a new portal.

Secondly, it is clear that students in this first year cell biology course are only moderately engaged in their learning in cell biology. For students to be successful in their learning, course engagement levels must be improved. The responsibility lies between both parties; the student and the educator. Students must focus on becoming more engaged on an emotional and participatory level and to value the learning that emanates from this. They must be aware that ritualistic study practices alone are not enough to be able to surpass the boundaries that may limit their conceptual understanding. Conversely, the educators in the life science disciplines must re-direct the course curriculum away from the ideas and theories presented incrementally and work towards activities that ask students to self-reflect and build an emotional engagement.

Lastly, a learner's experience does not originate and end at the classroom. There must be better societal pressure to prepare students entering higher education institutions but more importantly, learning in all aspects of life. Learning must be valued and approached from a holistic perspective that involves both the mind and the body. In some respects, we must return to learning for the sake of learning and de-emphasize short term rewards. We must find ways to stimulate a student's intrinsic motivation beyond good grades and aspiring career rewards.

5.4 Recommendations

Rationally, it is not possible to change all courses and curriculum merely at the suggestion of a threshold concept. Constraints may involve program requirements, limitations of the classroom environment, time and even attitudes toward education by the educators. However, I would recommend that smaller, incremental changes be implemented that can have a cumulative effect on the quality of the learning experience. The recommendations I will summarize fall into three levels; the course, the curriculum design and program design.

First of all, at the level of the course, I would recommend that the learning objectives and activities used in biology 112 be re-designed to focus specifically on the struggles that were reported with some of the threshold concepts. For example, one element of each activity would build upon the previous one to allow students to self-reflect on their initial understandings of a concept and re-visit. We also must allow time for students to struggle with the material such that they can cross conceptual boundaries within the time frame of the term and use class time to model behaviors in learning rather than presenting more material.

Additionally, I would recommend that students are given more opportunity to provide feedback and insight into the course. Students may voluntarily complete the course engagement questionnaire so as to provide instructors with a gauge to monitor student involvement throughout the term. More simply, students can be asked “How engaged are you in this class?”. The focus group interviews were informative to provide areas of difficulty but also a lens to how students are thinking and processing the material. The students were not hesitant in discussing what they did or did not understand. Using these threshold concepts to start, educators can ask students to provide anonymous feedback or structure interactions with groups of students to obtain this type of information.

At the level of curriculum design, I would recommend that the threshold concepts be used to structure the presentation of the course material so that not all difficult content falls into the latter half of the course. Educators should attempt to understand the pitfalls and triggers that are involved in students crossing the conceptual thresholds and use that as a tool to develop content. Although the acknowledgement of a threshold concept alone should provide an impetus for curriculum change, the implications are that faculty developers now have an obligation to put threshold concepts into practice. Faculty educators must address student difficulties by assisting transitions from surface to deep learning and transformational learning by providing the strategies to deal with these threshold concepts.

Finally, for program design, educators should be provided with opportunities to explore the deeper understandings of threshold concepts in a program. It can be suggested that the notion of a threshold concepts may be itself a threshold concept for some educators. It may be prudent for educators to step back and examine some aspects of a program to gain an appreciation for the learning process. As most university level programs build upon lower level courses, it is of utmost importance that students demonstrate mastery before they reach upper level courses.

5.5 Future directions

To add to the transformative experiences of a first year student, future studies in examining learning outcomes would benefit both students and educators. For example, this study was limited to comparing student success to overall performance on multiple choice exams. It would be beneficial to examine and document students as they progress in their learning using specific problems that relate to these threshold concepts. Future studies could also examine the impact of other threshold concepts identified in the "Framework for threshold concepts" (Chapter 4, Table 4.2). Most importantly, it would be beneficial for a study to develop course material and activities that can measure and assure a degree of success in mastering threshold concepts.

5.6 Conclusions

A few solid conclusions can be drawn from this study. Threshold concepts can provide a foundation to examine areas of conceptual difficulty and build upon the framework proposed in

Chapter 4, “Framework for threshold concepts in cell biology” (Table 4.2). The threshold concepts identified in this study are tools where educators in the cell biology course can improve the classroom experience and model expert learning behaviors. Students in first year cell biology were determined to be engaged in their learning only at moderate levels and their engagement focused on specific study skills and performance behaviors. Emotional engagement in the course material is important for students to experience a transformative learning experience and cross the conceptual threshold to enter a new portal or gateway of understanding. To improve overall engagement levels and especially those involving emotional and participatory engagement in the material, educators must model and design course curriculum to reflect this type of behavior. Last by not least, first year educators need to establish a continuous dialogue with their students to examine how difficult content is processed and establish if mastery is actually achieved.

References

Ambrose, S.A., Bridges, M., DiPietro, M., Lovett, M. & Norman, M. (2010). *How Learning Works: Seven Research-Based Principles for Smart Teaching*. San Francisco, CA: Jossey-Bass.

Anderberg, E., Alvegård, C., Svensson, L., & Johansson, T. (2009). Micro processes of learning: exploring the interplay between conceptions, meanings and expressions. *Higher Education*, 58(5), 653-668. doi:10.1007/s10734-009-9217-x

Anderson, W.L., Sensibaugh, C.A., Osgood, M.P., Mitchell, S.M. (2011). What Really Matters: Assessing Individual Problem-Solving Performance in the Context of Biological Sciences. *International Journal for the Scholarship of Teaching and Learning,* 5(1). Retrieved from: http://academics.georgiasouthern.edu/ijsotl/v5n1.html

Barefoot, B. O. (2000). The First-Year Experience. *About Campus*, 4(6), 12. Retrieved from EBSCO*host*.

Beattie, V., Collins, B. & McInnes, B. (1997). Deep and surface learning: a simple or simplistic dichotomy?. *Accounting Education*, 6(1), 1-12. doi:10.1080/096392897331587.

Biggs, J., Tang, C. (2007). *Teaching for Quality Learning at University: What the Student Does* (3rd Edition). P. 357. Open University Press, Buckingham, U.K. Retrieved from: http://site.ebrary.com/lib/ubc/docDetail.action

Bradbeer, J. (2006). Threshold concepts within the disciplines. *Planet,* No. 17, pp. 4 – 5. Retrieved from http://www.gees.ac.uk/planet/p17/jb.pdf

Barkley, E.F. (2010). *Student engagement techniques: a handbook for college faculty*. San Francisco: Josey-Bass

Brinkworth, R., McCann, B., Matthews, C. & Nordström, K. (2009). First year expectations and experiences: student and teacher perspectives. *Higher Education*, 58(2), 157-173. Doi:10.1007/s10734-008-9188-3

Brown, S.W. & Schrader, P.G. (2008). Evaluating the first year experience: students' knowledge, attitudes, behaviors. *Journal of Advanced Academics*, 19(2), 310 -343. doi: 10.4219/jaa-2008-77

Brownlee, J., Walker, S., Lennox, S., Exley, B. & Pearce, S. (2009). The first year university experience: using personal epistemology to understand effective learning and teaching in higher education. *Higher Education*, Vol. 58 Issue 5, 599-618. doi: 10.1007/s10734-009-9212-2

Butler, D., Nakonechny, J., Nomme, K., & Pollock, C. (2008) Promoting authentic Inquiry in the sciences: challenges faced in redefining university students' scientific epistemology. In Aulls, M., Delcourt, M., & Shore, B., (Eds.), *Inquiry in education, vol II. Overcoming barriers to successful implementation (pp. 30 –324)*. New York, NY: Taylor & Francis

Collins, J.B. & Pratt, D.D. (2011). The Teaching Perspectives Inventory at ten years and one hundred thousand respondents: reliability and validity of a teacher self-report inventory. *Adult Education Quarterly*, pp. 1-18. doi: 10.1177/07413610392763

Cousin, G. (2006). An introduction to threshold concepts. *Planet,* No. 17, pp. 4 – 5. Retrieved from http://www.gees.ac.uk/planet/p17/gc.pdf

Davies, P., & Mangan, J. (2007). Threshold concepts and the integration of understanding in economics. *Studies in Higher Education,* 2007. 32(6), pp 711-726 doi:10.1080/03075070701685148

Davies, P., & Mangan, J. (2005). Recognizing threshold concepts: an exploration of different approaches. *Embedding Threshold Concepts.* Working Paper 2 from http://www.staffs.ac.uk/schools/business/iepr/info/Economics(2).html

Floyd, K. S., Harrington, S. J., & Santiago, J. (2009). The effect of engagement and perceived course value on deep and surface learning strategies. *Informing Science*, 12181-190. Retrieved from EBSCO*host*.

Giordano, P. J. (2010). Serendipity in teaching and learning: The importance of critical moments. *Journal on Excellence in College Teaching, 21* (3), 5-27. Retrieved from: http://celt.muohio.edu/ject/index.ph

Gurung R. A., Weidert J., & Jeske,A. (2010). Focusing on how students study. *Journal of the Scholarship of Teaching and Learning,* Vol. 10, No. 1, January 2010, pp. 28 - 35. Retrieved from: https://www.iupui.edu/~josotl/

Haggis, T. (2003). Constructing Images of Ourselves? A Critical Investigation into 'Approaches to Learning' Research in Higher Education. *British Educational Research Journal*, 29(1), 89. Retrieved from EBSCO*host*.

Handelsman, M.M., Briggs, W.L., Sullivan, N., & Towler, A.. (2005). A measure of college student course engagement. *The Journal of Educational Research*, 98(3), 184-191. Retrieved from: http://cte.uwaterloo.ca/KSU/Donna%20Motivating%20Students/Handelsman%20et%20al.pdf

Hay, D. B. (2007). Using concept maps to measure deep, surface and non-learning outcomes. *Studies in Higher Education*, 32(1), 39-57. Retrieved from EBSCO*host*.

Hazel, E. (2002). Variation in learning orchestration in university biology courses. *International Journal of Science Education*, 24(7), 737-751. doi:10.1080/09500690110098886.

Hubball, H.T. & Clarke, A. (2010a). Diverse methodological approaches and considerations for conducting the scholarship of teaching and learning in higher education. Canadian *Journal for the Scholarship of Teaching and Learning* 1(1). Retrieved from: https://www.iupui.edu/~josotl/

Huy Phuong, P. (2011). Interrelations between self-efficacy and learning approaches: a developmental approach. *Educational Psychology*, 31(2), 225-246. doi:10.1080/01443410.2010.545050.

Kidwell, K.S. & Reising, B. (2005). Understanding the college first-year experience. *Clearing House*, Jul/Aug2005, 78 (6), 253-255. doi:10.3200/TCHS.78.6.253-256

Kinchin, I.M. (2010). Solving cordelia's dilemma: threshold concepts within a punctuated model of learning. *Journal of Biological Education*, 44(2), 53-57. Retrieved from EBSCO*host*.

Land, R., & Meyer, J.H.F. (2003). Threshold concepts and troublesome knowledge (1): linkages to ways of thinking and practicing within the disciplines. *Improving Student Learning – Ten Years On*, 2003. C. Rust (Ed). doi: 10.1007/s10734-004-6779-5

Land, R., & Meyer, J.H.F. (2005). Threshold concepts and troublesome knowledge (2): epistemological considerations and a conceptual framework for teaching and learning. *Higher Education,* 2005 (49), pp 373 – 388. dx.doi.org/10.1007/s10734-004-6779-5.

Lee, M.K., Erdogan, I. (2007). The effect of science-technology-society teaching on students' attitudes towards science and certain aspects of creativity. *International Journal of Science Education, 29*(11) pp.1315-1327. doi**:**10.1080/09500690600972974

Lindgren, C. (2010). Turning Biology Education Upside Down. *Chronicle of Higher Education*, 56(35), A27. Retrieved from EBSCO*host*.

Lucas, U., & Mladennovic, R. (2007). The potential of threshold concepts: an emerging framework for educational research and practice. *London Review of Education*, 5(3), pp237 – 248. doi:10.1080/14748460701661294.

Lumsden, P. (2011). Student engagement with learning; using student reflections to inform practice. *The Higher Education Academy -UK centre for biosciences.*

Mellanby, J., Cortina-Borja, M., & Stein, J. (2009). Deep learning questions can help selection of high ability candidates for universities. *Higher Education*, 57(5), 597-608. Doi:10.1007/s10734-008-9164-y

Mezirow, J. (2003). Transformative learning as discourse. *Journal of Transformative Education* 1 (1), January 2003, 58-6. doi: 10.1177/1541344603252172

Morris, M. M., & Puttee, C. (2006). Trawling for deeper learning. *International Journal of Learning*, 13(5), 137-146. Retrieved from EBSCO*host*.

Nelson, J., Robison, D.F., Bell & J.D., Bradshaw, W.S. (2009). Cloning the professor, an alternative to ineffective teaching in a large course. C*ell Biology Education: Life Science Education*. 2009 Fall; 8(3): 252–263. doi: 10.1187/cbe.09-01-0006.

National Survey of Student Engagement. (2010). *Major differences: Examining student engagement by field of study—annual results 2010*. Bloomington, IN: Indiana University Center for Postsecondary Research. Retrieved from: http://nsse.iub.edu/NSSE_2010_Results/pdf/NSSE_2010_AnnualResults.pdf

Pang, M., To Ming, H., & Man, R. (2009). Learning approaches and outcome-based teaching and learning: a case study in Hong Kong, China. *Journal of Teaching in International Business*, 20(2), 106-122. doi:10.1080/08975930902827825.

Palmer, D. (2005). A motivational view of constructivist informed teaching. *International Journal of Science Education*, 27(15), 1853-1881. doi:10.1080/09500690500339654.

Perkins, D. (2008). Beyond understanding. In R. Land, J. H.F. Meyer, J, Smith (Eds.), *Threshold concepts within the disciplines (pp. ix-3).* The Netherlands: Sense Publishers.

Perkins, D., (1999). The many faces of constructivism. *Educational Leadership*, 57(3). Retrieved from EBSCO*host*.

Pitkethly, A. & Prosser, M. (2001). The first year experience project: a model for university-wide change. *Higher Education Research & Development*, 20(2), 185-198. doi:10.1080/07294360120064420.

Pratt, D. (1997). *Five Perspectives on Teaching in Adult and Higher Education*, Krieger Publishing Company. Florida.

Pugh, K. J., Linnenbrink-Garcia, L., Koskey, K. K., Stewart, V. C., & Manzey, C. (2010). Motivation, learning, and transformative experience: a study of deep engagement in science. *Science Education*, 94(1), 1-28. Retrieved from EBSCO*host*.

Ross, P., Taylor, C. (2006). Threshold concepts in biology: do they fit the definition? In J.H.F. Meyer and R. Land (Eds). *Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge.* The Netherlands.

Ross, P., Taylor, C. (2010). Threshold concepts in biology: challenging the way we think, teach and learn in biology. In J.H.F. Meyer, R. Land and C. Baillie (Eds). *Threshold concepts and Transformational Learning*. The Netherlands.

Ross, P., Taylor, C. (2010). Threshold concepts in learning biology and evolution. *Biology International*, 2010. 47 Retrieved from: http://www.iubs.org/pdf/publi/BI/Vol%2047.pdf#page=49

Rowbottom, D.P. (2007). Demystifying threshold concepts. *Journal of Philosophy Education*, 41(2). doi.org/10.1111/j.1467-9752.2007.00554.x

Shulman, L. S. (1999). Taking learning seriously. *Change*, 31(4), 10. Retrieved from EBSCO*host*.

Shulman, L. S., & Shulman, J. H. (2008). How and what teachers learn: a shifting perspective. *Journal of Education*, 189(1/2), 1-8. Retrieved from EBSCO*host*.

Shulman, L. S. (2007). Good teaching. *Future of Children*, 17(1), 6. Retrieved from EBSCO*host*.

Smith, C.V & Cardaciotto, L. (2011). Is active learning like broccoli? Student perceptions of active learning in large lecture classes. *Journal of the Scholarship of Teaching and Learning*, 11 (1), January 2011, 53 – 61. Retrieved from: https://www.iupui.edu/~josotl/

Taber, K. S. (2008). Exploring conceptual integration in student thinking: evidence from a case study. *International Journal of Science Education*, 2008. 30(14). 1915- 1943. Retrieved from:http://cambridge.academia.edu/KeithTaber/Papers/591303/Exploring_conceptual_integration_in_student_thinking_Evidence_from_a_case_study

Taylor. J.L., Smith, K.M., van Stolk, A.P., Spiegelman, G.B. (2010). Using invention to change how students tackle problems. *CBE Life Science Education 2010* 9: 504-512. DOI:10.1187/cbe.10-02-0012

Tsay, M., Brady, M. (2010). A case study of cooperative learning and communication pedagogy: Does working in teams make a difference? *Journal of the Scholarship of Teaching and Learning,* Vol. 10, No. 2, June 2010, pp. 78 – 89. Retrieved from: https://www.iupui.edu/~josotl/

University of the Sciences in Philidephia (n.d.). *Teaching and learning activities*. Developing metacognition (or thinking about one's learning) skills. Retrieved from: http://www.usciences.edu/teaching/tips/activities.shtml#thinking.

Webb, G. (1997). Deconstructing deep and surface: Towards a critique of phenomenography. *Higher Education*, 33(2), 195-212. Retrieved from EBSCO*host*.

Wilson, A., Akerlind, G. (2010). Measurement uncertainty as a threshold concept in physics. *Proceedings of the 11th Uniserve Science Annual Conference*. Retrieved from: http://escholarship.usyd.edu.au/journals/index.php/IISME/article/viewFile/4686/547

Appendices

Appendix A: Focus group interview questions

Interviews were conducted in groups of 3 - 5 Participants:

Part 1: Exploration of students' engagement in the course material.

Aim: To explore how engaged students are in their learning in biology 112, I will use the validated 27 item *Student Course Engagement Questionnaire* (Handelsman et al, 2005). Each student in the focus group will complete this questionnaire on their own. See **Appendix B** for test item questions.

Part 2: A Review of Course Concepts - Activity

Aim: To explore students' self-reflection on their learning and their conceptual understandings that may illuminate areas of misconceptions.

The Activity: In their focus groups, students will be provided with 10 or more different concepts from the course. These will be written on index cards using terms and phrases the students are familiar with as a student in the course.

1. As a group, students will be asked to place each concept into two categories; content they felt they were able to grasp and understand well versus content they found difficult to grasp and understand.

Question: *"Consider the index cards placed before you. Each card represents an idea or concept you have been exposed to in this course. As a group, place each card into two different groupings; ideas and concepts that you feel you understand well and ideas and concepts you feel you did not understand well"*

2. Students will then be asked to rank the items for each group.

<u>Question:</u> "*For the first category (easiest to grasp and understand), which index card represents the idea or concept that was the* ***easiest to understand*** *for your group. Now rank the rest of the items in this category by placing the next easiest item to understand <u>above</u> the first card. Continue with each card in this category to create a tower. The highest card on the table should represent the least understood concept."*

"*For the second category (most difficult to grasp and understand) which index card represents the idea or concept that was the most difficult to understand for your group. Rank the remaining card items from the most difficult at the top and place the next card <u>underneath</u> creating a tower. The lowest card should represent the least difficult concept. You should now have all the cards in 2 lines on the table.*

3. Using 2- 3 of the index cards, students will be asked to reflect upon why they found the chosen concepts more difficult than others.

Question: "*Consider the first 2 cards at the top of each category. For all items, discuss why you considered these ideas/concepts more difficult than others.*

4. Students will be asked to reflect on related learning activities on 2-3 of the index cards.

Question: "*Consider the first 2 or 3 cards at the top of each category. For all items, do you recall any learning activities you did in this course that relates to that idea or concept? Was this activity helpful or unhelpful and why? Were there any other learning experiences you found helpful or not helpful?*

5. Last comments.

Question: "*Do you have any other comments you would like to share with regard to your learning experiences in this course?*

Appendix B: Student course engagement questionnaire

Threshold Concepts

"*An Investigation of Student Learning*
in a First Year Cell Biology Course".

This questionnaire is designed to explore how engaged you are in your learning in Biology 112. All responses are kept strictly confidential and will not identify you as a student.

Part I: Think about your experience in Biology 112. To what extent do the following behaviors, thoughts, and feelings describe you in the course? Please rate each of the statements by using the following scale:

1 = not at all characteristic of me

2 = not really characteristic of me

3 = moderately characteristic of me

4 = characteristic of me

5 = very characteristic of me

For each statement, check off one of the appropriate boxes.

	Not at all		Moderate		Very
1. Making sure to study on a regular basis	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
2. Putting forth effort.	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
3. Doing all the homework problems	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5
4. Staying up on all the readings.	❑ 1	❑ 2	❑ 3	❑ 4	❑ 5

1 = not at all characteristic of me

2 = not really characteristic of me

3 = moderately characteristic of me

4 = characteristic of me

5 = very characteristic of me

	Not at all		Moderate		Very
5. Looking over class notes between classes to make sure I understand the material	❑1	❑2	❑3	❑4	❑5
6. Being organized	❑1	❑2	❑3	❑4	❑5
7. Taking good notes in class.	❑1	❑2	❑3	❑4	❑5
8. Listening carefully in class.	❑1	❑2	❑3	❑4	❑5
9. Coming to class every day.	❑1	❑2	❑3	❑4	❑5
10. Finding ways to make the course material relevant to my life.	❑1	❑2	❑3	❑4	❑5
11. Applying the course material to my life.	❑1	❑2	❑3	❑4	❑5
12. Finding ways to make the course material interesting to me.	❑1	❑2	❑3	❑4	❑5
13. Thinking about the course between class meetings.	❑1	❑2	❑3	❑4	❑5
14. Really desiring to learn the material.	❑1	❑2	❑3	❑4	❑5

1 = not at all characteristic of me

2 = not really characteristic of me

3 = moderately characteristic of me

4 = characteristic of me

5 = very characteristic of me

	Not at all		Moderate		Very
15. Raising my hand in class.	❑1	❑2	❑3	❑4	❑5
16. Asking questions when I don't understand the instructor.	❑1	❑2	❑3	❑4	❑5
17. Having fun in class.	❑1	❑2	❑3	❑4	❑5
18. Participating actively in small group discussions.	❑1	❑2	❑3	❑4	❑5
19. Going to the professor's office hours to review assignments or tests or ask questions.	❑1	❑2	❑3	❑4	❑5
20. Helping fellow students.	❑1	❑2	❑3	❑4	❑5
21. Getting a good grade.	❑1	❑2	❑3	❑4	❑5
22. Doing well on the tests.	❑1	❑2	❑3	❑4	❑5
23. Being confident that I can learn and do well in class.	❑1	❑2	❑3	❑4	❑5

Part II: Answer the following questions using the scales provided below.

1. **How engaged are you in class?**
   Choose a value from 1 to 6 where 1 = not at all engaged and 6 = extremely engaged.
   Circle only one value.
   Not at all Extremely

2. **How engaged are you in this class, compared to the other courses you're taking this semester?**
   Choose a value from 1 to 6 where 1= less engaged than in any other of my courses and *6 = more engaged than in any of my other courses.* ***Circle only one value.***

3. **To what extent do you agree with the statement: "You have a certain amount of intelligence and you can't do much to change it".**
   Choose a value from 1 to 6 where 1= strongly agree and 6 = not at all agree.
   Circle only one value.

4. **If I had to choose between getting a good grade and being challenged in class, I would choose ____.**
   (insert "*good grade*" or *"being challenged"*).

Thank you for your responses.

Appendix C: Rankings of threshold concepts by focus group participants.
Students ranked items as most difficult (1) to least difficult (16).

Concept and Topics	**Focus Group** 1 n= 3	2 n= 5	3 n= 5	4 n= 3	5 n= 3	6 n= 3	7 n= 3	**Top Rankings* #**
Cell Size	10	15	15	16	13	14	15	
Cells are Microscopic	16	16	16	15	16	15	16	
Eukaryotic and Prokaryotic Cells	15	14	4	3	2	16	14	2
Polarity of Molecules	14	6	13	5	12	8	12	
Hydrophobic Effect	13	13	12	14	14	6	13	
Protein Structure	9	10	5	9	6	11	4	
Transport of Molecules In and Out of a Cell	4	8	9	7	11	13	11	
Enzymes as Catalysts	11	12	14	12	15	9	10	
Structure and Function of Nucleic Acids	12	5	11	13	10	4	9	
Directionality of DNA	5	9	10	10	9	12	8	
DNA Promoters	6	11	2	11	5	10	2	2
Transcriptional Control of gene expression	3	3	6	4	3	3	3	**5**
DNA synthesis	8	4	8	8	8	5	5	
Oxidation Reduction (redox) Reactions	1	2	3	6	7	1	6	**4**
Energetic Coupling	2	7	7	2	4	7	7	2
Cellular Respiration	7	1	1	1	1	2	1	**6**

Legend	**Rankings = 1 - 16**
n= number of participants	*1 = most difficult (hardest)* *16 = least difficult to understand* **Top Rankings** **Based rankings 1, 2 or 3.*

Appendix D: Student course engagement survey results (SCEQ)

Component I: Extent of engagement based on behaviors.
Factor – skills engagement items # 1- 9

Participants Coding	**Gender**	**Item 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
#1-2	2	4	5	4	5	2	4	3	4	5
#1-3	1	4	5	3	2	2	5	4	3	5
#1-5	1	5	5	3	5	4	5	2	4	4
#2-3	1	4	4	4	3	5	5	4	5	5
#2-1	1	4	4	5	5	4	5	5	5	5
#2-5	1	3	5	4	3	4	4	3	3	5
#2-2	2	4	4	2	3	5	3	3	3	5
#2-4	1	5	4	4	3	3	3	3	4	5
#3-4	1	3	4	2	2	4	5	4	5	5
#3-2	1	2	4	4	3	4	4	3	2	5
#3-3	2	2	3	3	3	3	3	3	4	5
#3-1	1	2	3	2	2	2	4	3	2	5
#3-5	1	5	5	5	4	5	5	5	5	5
#4-1	1	3	4	2	2	3	2	4	3	4
#4-2	1	2	2	2	2	3	1	4	4	5
#4-3	1	3	4	*	2	2	2	2	3	5
#5-2	2	5	5	5	4	3	4	3	4	5
#5-3	1	2	2	2	2	2	3	3	4	5
#5-4	1	4	4	3	5	3	5	4	3	5
#6-1	1	2	4	2	2	2	4	3	3	5
#6-2	1	2	3	4	2	2	4	3	3	5
#6-3	1	3	3	4	3	2	4	1	2	5
#7-1	2	4	4	4	4	3	4	4	4	5
#7-2	1	3	5	3	3	4	4	3	5	5
#7-3	1	2	3	3	3	2	3	4	5	2
Mean		3.28	3.92	3.29	3.08	3.12	3.80	3.32	3.68	4.80
Variance		1.21	0.83	1.09	1.16	1.11	1.17	0.81	0.98	0.42
Standard Deviation		1.10	0.91	1.04	1.08	1.05	1.08	0.90	0.99	0.65

Legend
* no response

Component I: Extent of engagement based on behaviors.

Factor – emotional engagement items #10 – 14.

Participants Coding	Gender	Item 10	11	12	13	14
#1-2	2	2	2	4	3	5
#1-3	1	1	2	3	2	3
#1-5	1	2	2	2	4	2
#2-3	1	2	2	3	4	3
#2-1	1	4	4	5	4	4
#2-5	1	5	5	4	3	2
#2-2	2	3	4	4	3	3
#2-4	1	3	2	3	2	3
#3-4	1	2	2	3	2	4
#3-2	1	2	2	3	3	3
#3-3	2	4	3	4	3	3
#3-1	1	3	3	3	3	1
#3-5	1	2	2	3	4	5
#4-1	1	5	4	4	3	3
#4-2	1	2	2	2	2	3
#4-3	1	3	3	3	3	2
#5-2	2	3	3	4	5	5
#5-3	1	1	1	1	2	2
#5-4	1	2	3	3	4	3
#6-1	1	3	3	2	2	4
#6-2	1	2	1	4	3	4
#6-3	1	2	2	2	1	4
#7-1	2	3	3	4	3	4
#7-2	1	3	2	4	2	3
#7-3	1	2	2	4	2	4
Mean		2.64	2.56	3.24	2.88	3.28
Variance		1.07	0.92	0.86	0.86	1.04
Standard Deviation		1.04	0.96	0.93	0.93	1.02

Component I: Extent of engagement based on behaviors.

Factor – participation and interaction engagement items #15 - 20

Participants Coding	Gender	Item 15	16	17	18	19	20
#1-2	2	4	4	5	5	5	4
#1-3	1	2	3	3	3	1	5
#1-5	1	1	2	3	5	3	4
#2-3	1	1	2	3	3	1	4
#2-1	1	3	5	5	5	4	4
#2-5	1	2	3	3	3	3	3
#2-2	2	2	3	3	2	2	4
#2-4	1	2	2	3	4	1	3
#3-4	1	3	1	4	4	2	4
#3-2	1	1	2	2	3	1	2
#3-3	2	3	3	2	4	2	4
#3-1	1	1	3	3	4	4	3
#3-5	1	1	2	3	5	1	3
#4-1	1	2	3	3	5	1	4
#4-2	1	2	2	4	4	3	3
#4-3	1	1	2	3	5	1	3
#5-2	2	2	3	4	5	3	4
#5-3	1	1	1	3	3	1	3
#5-4	1	1	2	3	3	2	4
#6-1	1	1	2	4	5	1	3
#6-2	1	1	3	4	4	1	4
#6-3	1	1	3	1	2	1	2
#7-1	2	3	4	3	4	3	4
#7-2	1	1	3	4	4	1	4
#7-3	1	1	1	2	3	1	2
Mean		1.72	2.56	3.20	3.88	1.96	3.48
Variance		0.79	0.92	0.83	0.94	1.46	0.59
Standard Deviation		0.89	0.96	0.91	0.97	1.21	0.77

Component I: Extent of engagement based on behaviors.

Factor – performance engagement items #21 - 23

Participants Coding	Gender	Item 21	22	23
#1-2	2	4	4	4
#1-3	1	4	4	4
#1-5	1	5	5	5
#2-3	1	4	3	3
#2-1	1	4	4	5
#2-5	1	4	4	4
#2-2	2	3	3	4
#2-4	1	3	3	3
#3-4	1	4	4	4
#3-2	1	3	3	3
#3-3	2	4	4	3
#3-1	1	1	1	1
#3-5	1	5	5	5
#4-1	1	4	4	5
#4-2	1	3	2	2
#4-3	1	4	4	4
#5-2	2	5	5	5
#5-3	1	3	3	3
#5-4	1	4	4	4
#6-1	1	1	1	1
#6-2	1	3	3	5
#6-3	1	3	3	4
#7-1	2	4	4	3
#7-2	1	3	2	4
#7-3	1	3	3	5
Mean		3.52	3.40	3.72
Variance		1.01	1.17	1.38
Standard Deviation		1.00	1.08	1.17

Component I: Extent of engagement based on behaviors.

Total scores

Participants	Gender	Part I: Total
Coding		**115**
#1-2	2	93
#1-3	1	74
#1-5	1	83
#2-3	1	78
#2-1	1	103
#2-5	1	83
#2-2	2	77
#2-4	1	72
#3-4	1	78
#3-2	1	65
#3-3	2	77
#3-1	1	60
#3-5	1	91
#4-1	1	78
#4-2	1	62
#4-3	1	65
#5-2	2	96
#5-3	1	54
#5-4	1	79
#6-1	1	61
#6-2	1	71
#6-3	1	59
#7-1	2	87
#7-2	1	76
#7-3	1	63
Mean		75.40
Variance		157.58
Standard Deviation		12.55

T-test comparison for component I factors

Factor 1	Factor 2	T-test (p value)
Skills	Emotional	<0.05
Skills	Participation/Interaction	<0.05
Skills	Performance	0.77
Emotional	Participation/Interaction	0.38
Emotional	Performance	<0.05
Participation/Interaction	Performance	<0.05

SCEQ - Components II –V results.

Participants	Gender	Component II	III	IV	V
Coding		scale 1-6	scale 1-6	scale 1-6	1 or 2
#1-2	2	5	4	3	1
#1-3	1	4	3	2	1
#1-5	1	4	4	5	1
#2-3	1	4	4	3	1
#2-1	1	5	4	6	2
#2-5	1	5	4	5	1
#2-2	2	4	5	2	1
#2-4	1	4	5	3	1
#3-4	1	4	5	5	1
#3-2	1	3	1	3	1
#3-3	2	4	1	4	2
#3-1	1	2	2	4	1
#3-5	1	5	6	5	2
#4-1	1	4	2	5	2
#4-2	1	4	5	6	1
#4-3	1	4	4	5	2
#5-2	2	4	2	6	1
#5-3	1	4	4	5	1
#5-4	1	4	5	5	1
#6-1	1	2	2	6	1
#6-2	1	4	4	3	1
#6-3	1	2	1	6	1
#7-1	2	3	3	5	1
#7-2	1	4	4	6	1
#7-3	1	4	2	5	1
Mean		3.84	3.44	4.52	1.20
Variance		0.72	2.09	1.68	0.17
Standard Deviation		0.85	1.45	1.29	0.41

Legend
II - Self-reported level of course engagement.
III - Self-reported engagement level as compared to other classes.
IV - Belief in learning theory – can intelligence be changed?
Scale 1 – 6
1 = strongly agree, 6 = not at all agree

V- Goal orientation – 1= choose between good grade vs. 2 = being challenged

Appendix E: Focus group exam performance

Average exam scores for focus group participants (74.5%)
and Biology 112, Fall term 2011 exam average (66.9%)

Participant Code	Overall Exam Scores* %
#1-2	84.2
#1-3	63.5
#1-5	95.2
#2-3	75.4
#2-1	84.7
#2-5	94.0
#2-2	81.6
#2-4	61.8
#3-4	72.2
#3-2	93.2
#3-3	77.3
#3-1	46.1
#3-5	91.3
#4-1	79.7
#4-2	66.6
#4-3	76.9
#5-2	77.4
#5-3	73.0
#5-4	59.4
#6-1	83.7
#6-2	66.4
#6-3	56.5
#7-1	89.2
#7-2	50.5
#7-3	63.4

*Correlation of exam scores and score Component I, based on extent of engagement based on behaviors in (items 1- 23)
$r = 0.47$

Appendix F: Letter of consent

T H E U N I V E R S I T Y O F B R I T I S H C O L U M B I A

Consent Form

An Investigation of Student Learning Using Threshold Concepts in a First Year Cell Biology Course.

Principal Investigator:

Dr. Harry Hubball
Dept. of Curriculum and Pedagogy, U.B.C

Co-Investigator:
Mrs. Karen Smith
Dept. of Microbiology and Immunology, U.B.C.
Dept. of Curriculum and Pedagogy, MA candidate

Purpose:

The purpose of this study is to examine university students' understanding of concepts in a cell biology course that are central to the course. This study will explore concepts that are particularly difficult for students and by way of focus group interviews, gain insight as to how students understand these concepts. You are being invited to take part in this research study because students attending university for the first time may have difficulties with concepts taught at the university level. Your feedback will provide insight as to the effectiveness of learning strategies, assignment and activities you have participated in as a student in Biology 112. This study is part of a graduate degree program in Curriculum and Pedagogy and is part of a thesis document.

Study Procedures:

Your participation will involve completing a 30 minute student course engagement questionnaire in addition to attending a 60 minute focus group interview. Interviews will be conducted in groups of five students and typically will last no more than one hour.

This research involves the analysis of tests and activities that are a part of your regular class routine in Biology 112. The results of those who do not participate will not be included in the research.

Participants will be selected based on the criteria that they are registered in Biology 112 in term 1 of winter session 2011, are attending university for the first time, registered in a first year science program in the life sciences and have attended a secondary institution (high school) in British Columbia. At the time of recruitment, researchers will ask students for their ID numbers and permission to review their background information for this purpose of participant selection.

Potential Risks:

There are no known risks to participation in this study.

Potential Benefits:

The benefits to you are indirect; the results of these interviews are part of a course goal to improve science education. Input from the interviews is an essential component in understanding what changes in educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.

The benefits to society in general will be improved science education that most students will find more interesting and relevant to their lives.

Confidentiality:

Your confidentiality will be respected. Interviews will be transcribed and no one except the researchers will have access to your identity. The interviewer will be a faculty or staff researcher from the participating department with expertise in the respective discipline. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet. Any information in electronic format will be stored on password protected computers. No individual student identifiers will be used in any published or publicly presented work.

Since interviews will be conducted as focus groups, only limited confidentiality can be offered as we cannot control what other participants do with the information discussed. We encourage all participants to refrain from disclosing the contents of the discussion outside of the focus group; however, we cannot control what other participants do with the information discussed.

Remuneration/Compensation:

For your participation, you will receive compensation of $10 gift certificate.

Contact for information about the study:

If you have any questions or would like further information about this study, you may contact the researchers as follows:

Harry Hubball

Karen Smith

Contact for concerns about the rights of research subjects:

If you have any concerns about your treatment or rights as a research subject, you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598 or if long distance e-mail to RSIL@ors.ubc.ca.

Consent:

Your participation in this study is entirely voluntary and you may refuse to participate or withdraw from the study at any time without jeopardy to your class standing.

*If you require additional time to review this consent form, please feel free to do so and return the signed form to the appropriate researcher by the first meeting.

Your signature below indicates that you have received a copy of this consent form for your own records.

Your signature indicates that you consent to participate in this study.

____

Participant's Signature

Date

____

Printed Name of the Participant signing above.