INVESTIGATING UNDERGRADUATE STUDENTS' METACOGNITIVE TRANSFORMATIONS IN AN INTRODUCTORY ORGANIC CHEMISTRY COURSE

by

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Abstract

Recently, there has been a considerable number of curricular and pedagogical reform efforts in undergraduate science education to shift from traditional methods of lecturing and assessment to more active, learning-centered environments. While these shifts have introduced significant improvements in students' conceptions of and engagement with science, the importance of *how* students learn science is often overshadowed. More specifically, there exists a need to address and enhance students' metacognitive knowledge and regulation to assist them in effectively monitoring, evaluating, and planning their learning. This study investigated the catalysts that influenced students' metacognitive transformations in an introductory organic chemistry course for biological science majors. A case study approach employing a combination of surveys, classroom observations, and interviews was used to investigate: 1) the catalysts (and their characteristics) influencing students' metacognitive transformations; 2) the role of social environments in these transformations; and 3) the supports/barriers various groups of students perceived as influential to their metacognitive transformation. Analysis of the data corpus suggested performance-based assessment methods as the most influential to students' metacognitive transformations and as overshadowing the resources designed to enhance students' metacognition and self-efficacy. Despite the desire to engage students with their learning, the results from the SEMLI-S (Self-Efficacy and Metacognition Learning Inventory – Science) survey revealed a significant drop in students' ability: to connect constructively with the course material; to effectively monitor, evaluate, and plan their learning; and to be confident in their ability to succeed in the course. Students attributed their lack of prerequisite content and metacognitive knowledge and the overwhelming quantity of course content as constraining their ability to actively engage in their learning. Some students, however, successfully employed metacognitive

strategies and offered explicit descriptions of how and why they developed and/or adapted their learning strategies prior to or during the course of the semester. This study also provided insight into how students perceived and negotiated their learning, both individually and collaboratively. The findings from this study have implications on how undergraduate science curriculum and pedagogy might embrace learner-centered pedagogies to enhance students' metacognition and self-efficacy.

Preface

This dissertation is based on work I conducted as Graduate Research Assistant with the Carl Wieman Science Education Initiative (CWSEI) at the University of British Columbia (UBC). I was the primary researcher for this study and administered and analyzed the surveys, classroom observations, and interviews. This research study obtained approval of the UBC Research Information Services Research Ethics Board (Behavioural Research Ethics Board Certificate #H13-01787).

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CHEM 200: A pseudonym for the second year introductory organic chemistry course for biological science majors

UBC: The University of British Columbia

SEMLI-S: Self-Efficacy and Metacognition Learning Inventory – Science

CC: Constructivist Connectivity

MEP: Monitoring, Evaluation, and Planning

AW: Learning Risks Awareness

CO: Control of Concentration

SE: Self-Efficacy

UMd-PERG: University of Maryland Physics Education Research Group

Glossary

Metacognition: the awareness and knowledge to control, evaluate, plan, and monitor one's learning processes.

Self-Efficacy: One's confidence in being able to achieve particular learning or course goals.

Awareness: One's consciousness about the way they learn, construct knowledge, or develop an understanding.

Control: The ability to consciously self-regulate one's learning processes.

Evaluation: The ability to assess the effectiveness of one's learning prosses.

Monitoring: The ability to keep track of one's learning processes by judging whether ideas or concepts make sense within a given framework.

Planning: Organizing how one might approach their studying or tackle a given learning task.

Catalysts: Moments, events, interactions, or resources that might trigger students to transform their strategies/knowledge or to develop an awareness of their ability as a learner.

Metacognitive Transformations: A significant change (either positive or negative) in students' awareness of or strategies for controlling, monitoring, planning, and evaluating their learning processes.

Flipped Classroom: The central idea of this is that students' are exposed to the bulk of the course content outside of lecture (via technological means such as recorded lecture) and that in class, students apply the material they have learned through complex problem-solving and peer instruction (Jensen, Kummer, & Godoy, 2015). As such, the student is responsible for attaining the content outside of class, and the instructor facilitates the application of this content within class. In traditional classrooms, these responsibilities are flipped in that the instructor is responsible for exposing students to the content in class and the students are responsible for applying this material outside of class (via assignments and problem sets).

Successful students: Students who entered the course with and/or who developed a metacognitive maturity over the course of the semester exhibited: a greater capacity to connect with the course material both inside and outside of class; descriptive, specific accounts about their knowledge and regulation of their strategies for learning; and an awareness of their strengths and weaknesses as learners.

Constructivist Connectivity: Whether a student makes connections between information and knowledge across science learning environments.

Control of Concentration: Whether a student controls their level of concentration when learning.

Learning Risks Awareness: Students' awareness to situations that may interfere with their learning.

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Dedication

To my Kiwi.

Chapter 1: Introduction

1.1 Background

For a long time undergraduate science teaching was dominated by traditional, knowledge-based science curricula and pedagogies. Moreover, the focus of these curricula and pedagogies was primarily on performance outcomes with no attention paid to *how* students engage in and learn science (DeBoer, 1991; Thomas, 2012; Wieman, 2007; Wright, Sunal, & Day, 2004). In recent years, however, several initiatives have been undertaken to reform the way science education is facilitated at the undergraduate level (Baird & Mitchell, 1987; DeBoer, 1991; Henderson, Finkelstein, & Beach, 2010; Wieman, Perkins, & Gilbert, 2010). Consequently, instructional approaches encouraging active learning and reflection are becoming increasingly common within the undergraduate science classroom (Kalman & Milner-Bolotin, 2013; May & Etkina, 2002; Moll & Milner-Bolotin, 2009). They encourage students "to do meaningful learning activities and think about what they're doing" (Prince, 2004, p. 223). Within these environments, the role of the instructor is being redefined to that of a facilitator and a guide, enabling students to become active, independent, collaborative learners (Stage & Kinzie, 2009).

While these shifts in curriculum and pedagogy have revealed significant advancements in students' conceptions of and engagement with science, the importance of addressing and improving students' beliefs about and strategies for science learning have largely been ignored (Gunstone, 1994; Thomas, 2012; Wieman, 2012). As such, students are often unaware of when and why they need help and are unable to differentiate what they know and do not know, which represents a significant gap in their metacognitive knowledge and self-regulation (Ambrose et al., 2010; Kolencik & Hillwig, 2011; Thomas, 1999; Tobias & Everson, 2002). Even when students are aware that a strategy or approach is ineffective, they often "cannot break their fixation on this approach to develop a more worthwhile plan" (Davidson & Sternberg, 1998, p. 58).

Attention to this problem has been growing, with a call for instruction to include strategies that will enhance students' metacognition. Within this context, metacognition is about students having the awareness and knowledge to control, evaluate, plan, and monitor their learning processes (Ambrose et al., 2010; Anderson & Nashon, 2007; Gunstone, 1994; Tanner, 2012; Thomas, Anderson, & Nashon, 2008). In fact, a substantial amount of research exploring science learning has resulted in the conceptualization of several instructional and curricular models to enhance students' metacognition (Thomas, 2012; Veenman, 2012; White & Frederiksen, 1998). However, while these studies and models offer valuable insights into enhancing students' experiences with and reflections on metacognitive knowledge and self-regulation, students' metacognitive development during this process has not received ample attention (Case & Gunstone, 2002, 2006). Furthermore, within the literature it is still unclear what critical moments, interactions, activities, or discussions within a given discourse trigger transformation in students' metacognitive development.

1.2 Research Questions

In response to the aforementioned concerns, my doctoral research explores the catalysts that influence students' metacognitive transformations in a learner-centered introductory organic chemistry course for biological science majors. The catalysts are moments, events, interactions, or resources that influence students to change/adapt their strategies/knowledge or to develop an awareness of their ability as a learner. Learning and metacognition are often viewed from a personal lens and as such, it is important to consider how social environments can influence students' metacognitive transformations.

My research questions for this study are:

1. *What are the catalysts for metacognitive transformation during one semester of an introductory organic chemistry course for biological science majors?*
2. *What aspects/characteristics of the catalysts do students perceive as most influential to their metacognitive transformations?*
3. *To what extent do social environments influence the metacognitive transformations of students in an introductory organic chemistry course?*

The investigation of these first three questions provided a contextual perspective of the (social) resources, events, or interactions that students perceived as both impeding and enhancing their learning and led me to ask this final research question:

4. *What do students perceive as the barriers and enhancers to their metacognitive transformations and how do these barriers and enhancers manifest during Chemistry study discourse?*

This study used an interpretive (Creswell, 2009; Erickson, 1998; Green, Caracelli, & Graham, 1989; Mertens, 1998; Teddlie & Tashakkori, 2009; Treagust, Won, & Duit, 2014) case study approach (Merriam, 1988; Stake, 1995; Yin, 2003) framed within a constructivist paradigm (Anderson & Nashon, 2007; Anderson, Nashon, & Thomas, 2009; Lave & Wenger, 1991; Mertens, 1998; Thomas & Anderson, 2012) to explore the aforementioned research questions. It is also grounded in theory and research on metacognition (Anderson & Nashon, 2007; Flavell, 1976, 1979; Flavell, Miller, & Miller, 2002; Thomas et al., 2008), metacognitive development (Baird, 1990; Case & Gunstone, 2002, 2006), and social (meta)cognition (De Backer, Van Keer, & Valcke, 2012; Hurme, Palonen, & Jarvela, 2006; Levin & Wagner, 2009). The use of these theoretical and methodological frameworks helped me to better conceptualize and investigate how particular catalysts were influential to students' metacognitive transformations.

1.3 The Case

Two sections of a second year introductory organic chemistry course (CHEM 200) for biological science majors at the University of British Columbia were used as the case for my research. Introductory organic chemistry is a challenging, cumulative course that requires students to develop and/or adapt to a more complex set of learning strategies than those used in their previous chemistry courses. Unfortunately, many students fail to develop meaningful learning strategies and begin to fall behind in the course (Grove & Bretz, 2012; Lynch & Trujillo, 2011; Spencer, 2006; Zhao, Wardeska, McGuire, & Cook, 2014).

The instructor for these two CHEM 200 sections had been teaching the course for nine years and over that time had been continually developing and refining the course to actively engage students in their learning. Similar to most learner-centered scholars in undergraduate science (Laurillard, 2002; May & Etkina, 2002; Sunal et al., 2009; Wieman et al., 2010), one of the instructor's main goals was to help students become aware of and improve their strategies for learning organic chemistry. The course incorporated Peer Instruction (Mazur, 1997), homework learning activities, in-class quizzes, pre-class videos and quizzes, small group discussions, explicit study strategy activities, and, recently, a study strategy workshop intervention to engage students in the learning of organic chemistry. Each of these opportunities was designed to enhance student understanding while emphasizing the importance of learning and metacognitive strategies.

Despite refining the course for over nine years, the instructor claimed that students' performance in the course had not increased significantly. Informal interactions with the students revealed that the majority of students were struggling with developing effective study strategies and that they rarely sought out help to improve their situation. As a result of this concern, I was curious to explore the particular resources, events, or interactions students perceived as catalytic to their learning and metacognition. If we hope to improve student learning and experience in this course we must also consider how students' perceive themselves as learners.

1.4 Significance of the Study

This exploration will help to pinpoint and compare the usefulness of various resources, interactions, and/or events on students' experiences with becoming (or not becoming) metacognitive learners in an active, learner-centered classroom. This research will add to the existing literature on curricular and pedagogical reform in undergraduate science education. It will provide a descriptive account of how students engage or disengage with various catalysts both internally and externally to the course. An analysis of students' perceptions of their learning and experience will offer a contextual, complex view of the development of science students' metacognition and give new insight to the role that social environments play within science student learning.

1.5 Researcher Background

I bring to this research a passion for science education and literacy within the classroom and the community at large. My roles as a math and science student, tutor, technician, and educational research assistant/coordinator served as an impetus for a future career in teaching and learning within undergraduate science education. Furthermore, guidance from my professors and mentors were key factors influencing my pursuit of graduate work in science education at UBC.

My experiences throughout my undergraduate and graduate degrees have thrust me into teaching, learning, and research in undergraduate science. I completed a Bachelor of Science in Chemical Physics (Co-op) at the University of Guelph from 2002-2007 and during this time, was engaged with several curricular and pedagogical initiatives. Since

2008, I have completed a Master of Arts (MA) in Curriculum Studies (Science Education), have worked as a Graduate Research Assistant and Research Coordinator for the Carl Wieman Science Education Initiative (CWSEI, http://www.cwsei.ubc.ca/), co-instructed as a Teaching Assistant for a first-year scientific writing class, and have pursued a PhD in Curriculum Studies (Science Education) at UBC. As a graduate student situated in the Faculty of Education and at the same time researching within the CWSEI and the Faculty of Science, I have been exposed to the myriad of political, curricular, and pedagogical issues embedded within teaching and learning at UBC. Navigating these various environments have presented their own set of obstacles, but the experiences and interactions with administrators, faculty, staff, and students within various faculties and disciplines have provided significant opportunities for my growth as a researcher, teacher, and scholar. I have been fortunate that my efforts in teaching, learning, and research have been recognized through such awards as a 2013/2014 Killam Graduate Teaching Assistant Award and a doctoral scholarship (2011-2015) from the Social Sciences and Humanities Research Council of Canada (SSHRC). These awards have not only encouraged me to persevere with a career in university teaching and learning but also continue to fuel my appreciation and passion for science education research.

My research has centered primarily on exploring students' experiences and perceptions of teaching and learning within the Faculty of Science at UBC. Since 2008, I have conducted and collaborated with colleagues on several mixed methods studies and have shared the findings at various local, national, and international conferences, and through numerous publications (Birol, Han, Welsh, & Fox, 2013; Cassidy, Dee, Lam, Welsh, & Fox, 2014; Fox et al., 2014; Welsh, 2012, 2013). Within the past year, I have also become a resource for administrators and faculty within the Faculty of Science and the Centre for Teaching, Learning and Technology at UBC with regards to various aspects of educational research including ethics protocols and applications, qualitative research design/analysis, and student perceptions. My experiences have not only helped me to grow as an educator, but have also allowed me to develop professional relationships with and seek mentorship from several individuals. It is these interactions that have led me to pursuing this doctoral work.

One of the instructors of CHEM 200 and I have been colleagues for over five years and, despite our efforts to enhance student learning strategies in CHEM 200, several students still exhibit surface approaches to learning. Even within my MA work, 86% of 500 students I surveyed within the UBC Faculty of Science expressed struggling with developing the appropriate study habits/skills for achieving success. This concern led me to consult literature on metacognition and self-efficacy and to explore the catalysts influencing students' metacognitive transformations. Ideally, this information would help the instructor in pinpointing the aspects of the course (or beyond) that were the most influential to student learning strategies.

My background as a student, tutor, teacher, and researcher have helped me to better understand the learning experiences of students in CHEM 200 and beyond. It is the responses, behaviours, and engagement of the students that challenge me to ask more questions about how we can engage students to become metacognitive, confident learners, and to support instructors throughout this process.

1.6 Thesis Organization

This thesis is comprised of six chapters. Chapter 1 presents a brief introduction to curriculum reform in undergraduate science education, the problem and research questions driving this study, and the significance of the study. Chapter 2 provides a more comprehensive review of undergraduate science education reforms and alludes to the necessity for metacognition to act as a pillar in curricular and pedagogical movements.

The chapter continues by conceptualizing the role of metacognition and self-efficacy in (science) education and exploring how these learning constructs have been researched within science education. Chapter 3 provides the methodological grounding of this interpretive case study and describes the data collection methods and analysis in detail. This chapter also describes the ethical considerations and the limitations of the study. Chapter 4 presents the findings from the data collection methods: the Self-Efficacy and Metacognition Learning Inventory-Science (SEMLI-S) survey instrument; classroom observations; a midterm feedback survey; and one-on-one interviews. Chapter 5 triangulates and synthesizes the data and reveals emergent themes from the analysis. Finally, Chapter 6 provides an overall summary of what has been learned through the investigation of the research questions. It also presents possible implications for theory, practice, curriculum, and future research.

Chapter 2: Literature Review and Theoretical Framework

This chapter provides a background of curricular and pedagogical reforms in undergraduate science education and the role that metacognition plays within these reforms. I begin by reviewing the incentives and frameworks for curricular and pedagogical reforms that move from traditional forms of lecture towards more active environments designed to engage students in the learning process and in becoming more metacognitive. After this introduction, I critique how metacognition is framed and theorized within (science) education and review potential classroom models for explicitly embedding metacognition within undergraduate science curriculum and pedagogy. I also address the methodologies and methods that are commonly used in metacognitive research in science education. Finally, I conclude the chapter by describing how this literature review has informed the theoretical framework, design, and significance of this study.

2.1 Incentives and Frameworks for Curricular and Pedagogical Reforms

Moments in history, as well as the visions of various educators, have fueled curricular and pedagogical reforms in science education at the primary, secondary, and tertiary levels (Baird & Northfield, 1991; DeBoer, 1991; Stage & Kinzie, 2009). For instance, the launch of Russia's Sputnik in the fall of 1957 brought criticism to the American education system and led scholars to consider how they could bring vigour to science curriculum and pedagogy (DeBoer, 1991). This concern served as an impetus for the National Science Foundation (NSF) to fund and assess large-scale curricular reforms in elementary and secondary physics, biology, chemistry, and earth sciences from the late 1950s to the early 1970s. In line with the ideas presented by Schwab (1969), the goal of these reforms was to present scientific facts and evidence as fluid and to emphasize the overarching concepts, contexts, and processes driving scientific phenomena and research.

That together as a community, teachers and students should question, critique, and explore the complexities of science.

Although the incentive of such reforms was to help students understand and not memorize the material, the content was often too difficult for the "average" science student to comprehend (DeBoer, 1991; Linn, diSessa, Pea, & Songer, 1994). One of the main drawbacks of these science reforms was their emphasis on content and lack of attention to several fundamental aspects of curriculum and instruction, including students' interests, their readiness to learn, and their ability to communicate and apply what they had learned (Linn et al., 1994). Although the reforms did adapt the curriculum to focus on the process of *doing* science, addressing the process of *learning* science was not always explicitly addressed. This focus on content and knowledge (*what* to learn) often overshadows one of the integral components of educational reforms and programs aimed at improving science education: the *how* and *why* of learning. Wieman (2012) states that the "failure to understand this learning-focused perspective is also a root cause of the failures of many reform efforts" (p. 1). Thus, it is not only important to encourage the process of science (e.g. collaboration, expert-like thinking, problem-solving), but to include student learning as one of the primary pillars within the framework of science education. Lord et al. (2010) call for educational reforms that emphasize learning-centered curriculum and pedagogy that foster lifelong learning and that encourage students to be "curious, motivated, reflective, analytical, persistent, and flexible" (p. 381).

The lack of explicit attention to how students learn within curriculum and pedagogical reforms is not only an issue relevant to previous reforms, but to current reforms as well. While there has been steady growth in science education reform at the elementary and secondary levels, higher education has experienced a recent surge of educational reform. Undergraduate science education has been criticized for its positivistic, traditional pedagogies that emphasize the transmission of knowledge and for considering the learner/student as a passive recipient of that knowledge (Henderson et al., 2010; Laurillard, 2002; McDermott, 2013; Taylor, Gilmer, & Tobin, 2002). Consequently, educators are pushing for and exercising a learning-centered curriculum that engages students and the instructor in collaborative, active learning processes both inside and outside of the classroom (Sunal et al., 2009). Laurillard (2002) cautions however that “higher education cannot change easily”, and advises that “traditions, values, infrastructures all create the conditions for a natural inertia…Higher education should be reformed through pressure from within” (p. 3).

Critical systemic changes are required to provide incentives for faculty to address student learning directly in their courses through enhanced pedagogy and curriculum. Wieman (2007) expresses that:

> A necessary condition for changing college education is changing the teaching of science at the major research universities, because they set the norms that pervade the education system regarding how science is taught and what it means to “learn” science. These departments produce most of the college teachers who then go on to teach science to the majority of college students, including future school teachers. So we must start by changing the practices of those departments (p. 15).

Currently in many large research-intensive institutions there remains insufficient emphasis on educational outcomes in comparison to research (Wieman, 2012). Faculty members have the autonomy to decide whether or not they are interested in being part of a curricular or pedagogical reform and, if not provided the appropriate guidance or feedback, may discontinue their involvement (Henderson, Dancy, & Niewiadomska-Bugaj, 2012). DeHaan (2005) calls for the "creation of university-wide culture that encourages change instead of impeding it and for better mechanisms to inform scientists about education research and the instructional resources available to them" (p. 264). This reveals the importance of supporting faculty within educational reforms.

Wieman (2007) offers the following suggestions for individuals interested in reforming undergraduate science education within their course, department, or institution:

1. Address the course content to reduce cognitive overload.
2. Address and recognize the importance of students' beliefs about science and how they learn science.
3. Facilitate teaching that engages students, allows them to monitor their thinking, and provides feedback on their progress.
    a. Teachers should be familiar with pedagogical content knowledge (how to teach the content and how students' learn the content).
    b. Incorporate peer collaboration to allow students in large classes to provide students with more frequent feedback on their understanding/learning.
4. Use technology, such as electronic response systems (clickers) and computer simulations, to help support student learning.

In order to implement the above suggestions, it is critical for collaboration and shared resources to exist among administrators, faculty, staff, and students alike (Belzer, Miller, & Hoemake, 2003; Henderson et al., 2010; Hubball & Gold, 2007). Most importantly, a change within the departmental culture for mathematics and science education at large research-intensive universities is often required in order to adopt evidence-based teaching methods, to assess the outcomes of these methods, and to view teaching as a scholarly endeavour. Research and assessment reveals that "the more the department as a whole has been involved and seen this as a general department priority, the more successful and dramatic have been the improvements in teaching" (Wieman et al., 2010, p. 3). Successful departments in the Carl Wieman Science Education Initiative at the UBC support their faculty by compensating their involvement with a reduced teaching load and/or support from teaching assistants, science education specialists, or research assistants (Wieman et al., 2010). This additional support helps faculty to develop and adapt their curriculum and pedagogy to include interactive teaching methods, appropriate assessments for/of student learning, and opportunities for reflecting on the overall effectiveness of the transformation (Sunal et al., 2009). Faculty need continual feedback and guidance about the pedagogy and curriculum that drive the reform and how best to facilitate the goals of the reform within the classroom.

It is not only essential to help instructors address how students learn, but also to engage students in considering how they think they learn science best (Ambrose et al., 2010; Baird & Mitchell, 1987; DeBoer, 1991; May & Etkina, 2002). Students and faculty can often get caught up in viewing science content as more important than thinking about how they have come to know and have learned the content. Educators must facilitate and mentor students as they shift from the stereotypical model of lecturing to a more inclusive, learner-centered model that emphasizes student learning and accountability (Sunal et al., 2009; Wright et al., 2004). Students are key stakeholders in teaching and learning and their perceptions and engagement play a critical role in the success of educational reforms.

Students' preconceived beliefs about how they learn can actually limit or enhance their engagement with reformed or new curricula and pedagogies (Ambrose et al., 2010; DeHaan, 2005). Laurillard (2002) indicates that, "the knowledge that students bring to a course will necessarily affect how they deal with the new knowledge being taught…Each new course builds on an assumption about what the student has already mastered" (p. 25).

In conjunction with the need to change a departmental culture for curricular and pedagogical reform, there is also a need to change the classroom culture to accommodate/support students' preconceived notions about, and their new experiences with, learning science.

An example of curricular and pedagogical course reform.

The following section draws on work by Redish and Hammer (2009) and Meredith and Redish (2013) who reviewed the success and barriers to the University of Maryland Physics Education Research Group's (UMd-PERG) five-year project to reform a first-year physics course for life-science majors. It provides an insightful glimpse into the inner workings of the course reform and alludes to many of the concerns and suggestions noted earlier in this chapter.

This large service course was primarily attended by life science majors and was a program requirement. The increasing role of physics within biology research served as an impetus for the UMd-PERG to adapt their first-year physics course to be more cohesive with biology content and to emphasize the importance of broad thinking and learning skills in science research/learning at large. Meredith and Redish (2013) mention that "bringing a physics course into alignment with the needs of biology students is a subtle and complex activity" (p. 38-39). Furthermore,

> Every class not only contains its explicit content, but elements that are traditionally not made explicit in descriptions of the class – an *implicit curriculum*. For example, traditional instructors tend to assume that students learn how to think about and do scientific reasoning while doing traditional class activities, such as reading the text and doing end of chapter problems. Some students do learn this successfully, but research indicates that most do not and indeed, some pick up bad habits and

> inappropriate modes of thinking. We chose to focus the class on helping students learn how to learn science, content that is implicit in most courses and that the research convinced us needs to be addressed explicitly. (Redish & Hammer, 2009, p. 1)

The project adopted an epistemological framework that had both students and teachers address issues related to the nature of scientific knowledge and how we come to know and make sense of this knowledge. The authors criticize implicit curriculum that ignores student learning as it "encourages poor approaches to learning such as rote memorization and the denigration of everyday experiences an intuitions" (Redish & Hammer, 2009, p. 2). Ideas about epistemology, knowledge, problem-solving, and learning strategies were made explicit and collected through surveys, homework assignments, exams, in-class discussions, and one-on-one interviews with some students. The course incorporated Peer Instruction (Mazur, 1997) and Interactive Lecture Demonstrations (Sokoloff & Thornton, 1997) to engage students in predictions and discussions that challenge their knowledge and thinking. These types of activities pushed students to make sense of their ideas, to seek coherence, and to question their difficulties as learners.

Although there was a strong focus on enhancing students' ability to become reflective and critical learners, similar to the other reforms, students still displayed resistance. Students were unfamiliar with the structure and demands of this course as it was extremely different from the traditional science courses where lecturing was the main instructional technique. Some students found the reform too demanding and would "give up" by neglecting to solve difficult problems or errors within their homework and exams. Despite this resistance, the structure, curricula, and teaching methods used in this course helped many students significantly change their approaches to learning science; "students who stud[ied] by focusing on why they had missed problems and on refining their thinking and understanding almost always improve[d], sometimes very substantially" (Redish & Hammer, 2009, p. 10). Most importantly, students realized the importance of questioning and making sense of the content rather than just memorizing it.

This work by Redish and Hammer (2009) and Meredith and Redish (2013) not only describes the finer points of curricular and pedagogical reforms, but emphasizes the necessity for students to become aware of and reflect upon their abilities as science learners. More specifically, this work reflects the need for metacognition to act as one of the main pillars in undergraduate science education (DeHaan, 2005; Thomas, 2012; Zhao et al., 2014; Zohar & Barzilai, 2013).

2.2 Metacognition: A Word with Many Interpretations

Metacognition has consistently been referenced as a 'fuzzy' or 'murky' concept (Anderson et al., 2009; Hacker, 1998; Nielsen, Nashon, & Anderson, 2009; Thomas et al., 2008; Tobias & Everson, 2009; Veenman, 2012). Although there is no agreed upon definition of metacognition, several scholars have attempted to "cut through the fuzziness and look for characteristics that have stayed constant across disciplines and purposes" (Hacker, 1998, p. 3). In its most simplistic form, metacognition has been defined as 'thinking about thinking' or 'cognition about cognition' (Hacker, 1998; Thomas et al., 2008). Weinert (1987) referred to 'metacognitions' as second-order cognitions; namely thoughts about thoughts, knowledge about knowledge, or reflections about actions. Despite slight differences in perspectives, one thing is common amongst the definitions and discussions of metacognition – they all refer to the work of Flavell (1976, 1979, 1987) as the backbone of metacognitive work.

Introducing metacognition: John Flavell.

Flavell (1976, 1979, 1987) is well-known for his inception of and ideas about metacognition. Flavell (1976) early definition of metacognition refers to an individual's ability to monitor, regulate, and orchestrate their cognitive processes to attain a particular objective. This was further expanded into a model of cognitive monitoring that includes *metacognitive knowledge, metacognitive experiences,* and *metacognitive regulation* (Flavell, 1979, 1987; Flavell et al., 2002; Zohar & Barzilai, 2013).

Metacognitive knowledge is based on cognition and relates to knowledge about oneself as learner, knowledge about a particular task or goal, and knowledge about the strategies needed to achieve a particular task or goal (Flavell, 1979). Veenman (2012) expressed that people's metacognitive knowledge is rooted in and affected by their own belief system and their world knowledge. For instance, a student might perceive memorization as the best way to learn material because this is what they have done in the past (Ambrose et al., 2010). Ultimately, peoples' knowledge and beliefs about learning affect how they approach a particular task and the strategies they will use to achieve this task.

Flavell (1979) referred to *metacognitive experiences* as metacognitive knowledge that has entered consciousness; a cognitive or affective realization that you do or do not know how to approach a particular task. Zohar and Barzilai (2013) described these experiences as moments of realization during learning such as feeling confused or having an "aha" moment and coming to understand something. This type of experience often translates into students engaging with types of quality control checks that allow them to monitor, interpret, and respond to their metacognitive knowledge (Lai, 2011). That is, they engage with *metacognitive regulation or skills*.

Metacognitive regulation or skills are the skills a learner uses in order to plan, monitor, control, and evaluate their learning (Flavell et al., 2002; Veenman, 2012; Zohar & Barzilai, 2013). These skills include but are not limited to setting goals, selecting appropriate strategies/resources, being aware of personal strengths/weaknesses, and assessing progress via reflection or testing. Flavell (1987) expressed that, "cognitive strategies are invoked to *make* cognitive progress, metacognitive strategies to *monitor* it" (p. 909). For instance, a person may add two numbers to determine the value (cognitive strategy) but they may also double-check their addition to ensure their calculation was correct (metacognitive strategy). In this case, the metacognitive strategy monitors the original cognitive strategy. Flavell (1987) stated that the "purpose is no longer to reach the goal (cognitive strategy), but rather to feel absolutely confident that it has been reached (metacognitive strategy)" (p. 23).

Declarative, procedural, and conditional knowledge.

To build upon Flavell's notion of metacognitive knowledge, regulation, and experiences, scholars classified an individual's knowledge of cognition as declarative (knowing what), procedural (knowing how), and conditional (knowing when and why) (Lai, 2011; Schraw, 2009; Schraw, Crippen, & Hartley, 2006; Thomas & Anderson, 2012; White & Frederiksen, 1998). Figure 1 is a visual of how I perceive these classifications as mapping onto work by Flavell.

Declarative knowledge is the notion that a person needs to have knowledge about: themselves as a learner, the particular cognitive task, the demands of the task, and the strategies need to achieve that task (Schraw et al., 2006). A person's epistemological understanding, that is, the knowledge about the origin of his/her beliefs, can influence the learning process (Lai, 2011; Quintana, Zhang, & Krajcik, 2005). What a person knows or thinks about learning is constructed from his/her previous experiences both inside and outside of the classroom and plays an important role in their engagement in and perceptions of their learning (Lai, 2011).

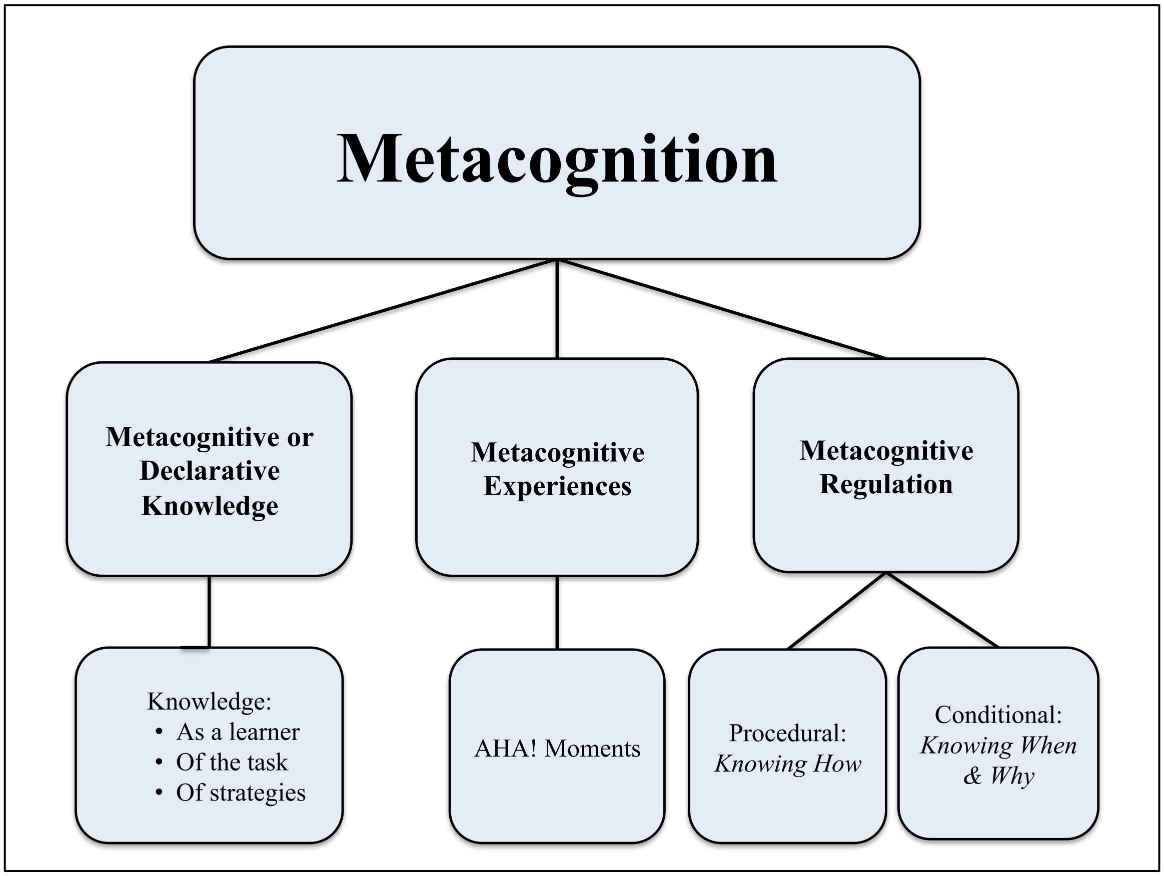

Figure 1 The relationship between various classifications of metacognition.

Procedural knowledge relates to how one might perform a learning activity (Thomas & Anderson, 2012) and is tied closely to conditional knowledge, which refers to knowing when and why to use this knowledge. The procedural presents *how* a person perceives they would approach a task best, while conditional knowledge depicts *when* they would use this task and *why* they perceive it would be appropriate. Aspects of procedural and conditional knowledge have also been embedded within what some scholars refer to as metacognitive regulation; the monitoring of one's own cognition (Lai, 2011). More substantially, scholars refer to metacognitive regulation as the planning, monitoring, and evaluation of the strategies and approaches that help students to guide their learning and cognition (Barak, 2011; Duncan & McKeachie, 2005; Schraw et al., 2006; Veenman, 2012).

2.3 Conceptualizations of Metacognition within the Literature

There appears to be shared language and ideas within the literature about metacognition. Table 1 summarizes some definitions and conceptualizations put forth by various scholars investigating metacognition. While metacognitive knowledge is considered a defining part of metacognition (Hacker, 1998; Schraw et al., 2006; Veenman, 2012) the majority of scholars appear to emphasize the regulatory aspects of metacognition. Terms such as monitor, plan, evaluate, regulate, and reflect, are used consistently by scholars – but each with their own flavor or interpretation. Often times the regulatory terms are interrelated and used in conjunction with one another. For instance, Quintana et al. (2005) emphasize the need for students to *plan* their learning by setting goals, to *monitor* the usefulness of their learning strategies, and to *regulate* this process by *evaluating* the speed and/or intensity of a given strategy. They also indicate that in order for someone to *monitor* and *regulate* their learning they should be able to identify the task they are undertaking, be able to *evaluate* their progress, predict the result of their work, and *reflect* on their learning process.

Table 1

Definitions and conceptualizations of metacognition

Authors	Definitions and Conceptualizations
Anderson et al. (2009); Anderson & Nashon (2007)	Active monitoring, conscious control, and regulation of learning processes.
Bandura (1993)	Selecting appropriate strategies, testing one's comprehension, correcting deficiencies, and realizing utility of strategies.
Duncan & McKeachie (2005)	Strategies that help students to control and regulate their learning (planning, monitoring, regulating).
Hacker (1998)	1. Knowledge of one's knowledge, processes, and cognitive and affective states. 2. Ability to consciously and deliberately monitor and regulate one's knowledge, processes, and cognitive and affective states.
Lai (2011)	Metacognitive knowledge: knowledge about oneself, strategies, when/why to use strategies. Metacognitive regulation: monitoring one's cognition through planning, awareness, and evaluation.
Nielsen et al. (2009)	Awareness and control of one's own learning processes.
Quintana et al. (2005)	Task understanding and planning, monitoring, regulation, and reflection.
Thomas et al. (2008)	Knowledge, control, and awareness of learning processes.
Thomas & Anderson (2012)	An individual's knowledge, control and awareness of their cognitive processes.
Schraw et al. (2006)	1. Knowledge of cognition: declarative, procedural, and conditional. 2. Regulation of cognition: planning, monitoring, evaluation.
Tobias & Everson (2002; 2009)	Ability to monitor, evaluate, and make plans for one's learning.
Veenman (2012)	1. Metacognitive knowledge: interplay between person, task, and strategy characteristics. 2. Metacognitive skills: monitoring, guiding, steering, and controlling one's learning behavior.
White & Frederiksen (1998)	Learning how to learn.

The diversity and similarities among the definitions of metacognition stress the need for scholars to operationalize the terms they are using. Research in science education by Anderson and Nashon (2007), Nielsen et al. (2009), and (Thomas et al., 2008) revealed six dimensions perceived as most important and useful for understanding and conceptualizing metacognition: awareness, control, evaluation, planning, monitoring, and self-efficacy. The definitions of these terms are summarized in **Table 2** and provide a clear and useful representation of the dimensions that encapsulate metacognition.

Table 2

Operationalized definitions of the six dimensions of metacognition from Anderson & Nashon (2007, p. 318)

Dimension of Metacognition	Operationalized Definition
Awareness	An individual's character of consciousness about the way he/she learns or constructs knowledge or develops understanding.
Control	An individual's self-regulation and executive control of his/her learning process. The individual consciously regulates and manages his/her learning process.
Evaluation	An individual's ability to assess the fruitfulness of the learning strategies he/she adopts. It is not about getting right/wrong answers. Rather, it is about strategies that are deemed by the learner to be successful.
Planning	An individual's awareness of his/her learning process that leads him/her to deliberately plan strategies for learning new information. The individual has a conscious awareness of where to start and where to look for tools to manage his/her learning.
Monitoring	An individual's ability to keep track of his/her learning process by ensuring that things make sense within the accepted cognitive frameworks. Judging whether understanding is sufficient and searching for connections and conflicts with what is already known.
Self-Efficacy	An individual's self-perceptions of one's capacity to learn, and includes how confident an individual is about the effectiveness of his/her learning process and the results of the learning process. It is about an individual's awareness of the fruitful nature of his/her learning process and the products thereof.

The first dimension, awareness, emphasizes the notion of consciousness; that a learner is aware of how they do or do not learn or understand a task. This parallels Hacker (1998) and Anderson et al. (2009) description of metacognition as a *conscious* and *deliberate* task, or as *active* monitoring and *conscious* control and regulation, respectively. Although the ability to control, evaluate, plan, and monitor one's learning is integral to being metacognitive, I perceive awareness as a critical dimension of metacognition. If a learner is not deliberate or conscious of their actions and strategies it may limit their ability to reflect upon and enhance their metacognitive strategies.

Beyond the main scope of metacognition, Anderson and Nashon (2007) also present self-efficacy, the level at which a student is confident in their ability to perform a given task. In science education, self-efficacy has been positioned with metacognition as a dimension influencing student learning (Anderson & Nashon, 2007; Thomas et al., 2008), whereas in psychology, self-efficacy is embedded within self-regulated learning as a component of motivation (Schraw et al., 2006). Explorations of self-efficacy in concert with metacognition have revealed, at both the individual and social level, the strong relationship between students' confidence and their engagement with various dimensions of metacognition (e.g. awareness, control, evaluation, planning & monitoring) (Anderson & Nashon, 2007; Schraw et al., 2006; Thomas et al., 2008).

This terminology carries over to the work of (Thomas et al., 2008) who created the SEMLI-S (Self-efficacy and Metacognition Learning Inventory – Science) to assess students' metacognition, self-efficacy, and constructivist science learning processes. The development of the instrument revealed five sub-scales that reflected dimensions of students' perceptions of their metacognitive science learning orientation. These dimensions include:

- **Constructivist Connectivity**: Explores whether students make connections between information and knowledge across science learning environments
- **Monitoring, Evaluation, and Planning**: Explores important, traditional strategies for learning science
- **Control of Concentration**: Explores whether students control their level of concentration
- **Learning Risks Awareness**: Explores students' awareness to situations that may interfere with their learning
- **Self-efficacy**: Explores students' confidence in being able to achieve learning/course goals

These dimensions include traditional dimensions/aspects of metacognition (monitoring, evaluation, planning, control, awareness), but also include the role that making external/internal connections and self-efficacy play within science student learning. In order to better understand this relationship, it is valuable to consider how metacognition and self-efficacy relate to and are embedded within other constructs of learning.

2.4 Metacognition and Student Learning

In recent literature, there is continued debate and discussion over metacognition and its relationships with other constructs that affect student learning (Schunk, 2008; Thomas & Anderson, 2012). Bandura (1993) expressed that learning is the result of several personal, environmental, and behavioral factors. Affective factors such as attitudes, motivations, interests, peer interactions, and expectations can play a role in learning (and science learning) (Yang & Tsai, 2012). Even Flavell (1987) proposed that future research should explore how metacognition relates to self-efficacy and self-regulation.

A review of the literature reveals two significant types of cognitive control processes with complex and overlapping characteristics: metacognition and self-regulated learning (Duncan & McKeachie, 2005; Schunk, 2008; Thomas & Anderson, 2012; Tobias & Everson, 2002). Thomas et al. (2008) state that:

> The relationships between metacognition and self-regulated learning and the actual learning processes that students employ should be acknowledged wherever possible because while it is often interesting and informative to look at metacognition as a 'stand-alone' concept, it does not influence learning outcomes in isolation but rather is related to other elements of learning theory. (p. 2)

In addition to metacognition, self-regulated learning explores the influences that cognition and motivation have on student learning (Bandura, 1993; Schraw et al., 2006; Tobias & Everson, 2002). Research in self-regulated learning is interested in examining and describing how a learner's thoughts, feelings, motivations, and actions play a role in their learning (Zimmerman & Moylan, 2009). Although scholars debate whether metacognition is secondary to self-regulated learning or vice versa, "irrespective of the precise relationship, research related to both constructs is concerned with understanding and improving students' learning processes and outcomes and deserves attention" (Thomas, 2012, p. 134).

Central to self-regulated learning is the construct of motivation; that students' willingness to learn and the effort they put into their learning can affect their overall performance and persistence. Weinert (1987) refers to metacognition as how a person's judgment corresponds to their abilities, learning strategies, or task difficulties, whereas motivation was concerned with how an individual's biases, behaviors, and experiences can affect the given task. For instance, in judging the difficulty of a task, metacognition research would concern itself with how the learner predicts their performance, the action plan they would create to approach the task, and their choice and use of particular strategies. Motivation research, on the other hand, would explore how learners' expectations, the allocation of their efforts, and their aspirations would influence their learning. Some scholars even claim that without appropriate motivation and desire students will not be effective at regulating their strategies and academic behavior (Tobias & Everson, 2002).

Although motivation and metacognition are tightly bound, Weinert (1987) provides a disclaimer that these constructs should be weighed differently depending on the research goals. Weinert encourages scholars to consider the theoretical underpinnings of the constructs under investigation and to evaluate and address their affordances, limitations, and connections. While there are many factors that contribute to student learning, within science education research, metacognition and self-efficacy have been regarded as key elements for successful learning outcomes (Anderson et al., 2009; Thomas & Anderson, 2012).

Metacognition and self-efficacy.

Self-efficacy, similarly to metacognition, is a type of self-appraisal or self-management (Anderson & Nashon, 2007; Barak, 2011; Hacker, 1998). The self-management of this appraisal has been referred to as "metacognition in action"; that a learner is aware of both their knowledge and affective states (Hacker, 1998, p. 11). Hacker (1998) presents metacognition and self-efficacy as integral constructs of learning that inform and relate to one another and that help learners to become actively involved in "the orchestration of their knowledge construction" (p. 11).

Self-efficacy has been referred to within the literature as a dimension of metacognition in science learning (Anderson & Nashon, 2007; Thomas et al., 2008) and as an aspect of self-regulated learning (Schraw et al., 2006; Thomas et al., 2008; Zimmerman & Moylan, 2009). For instance, within the science education literature, scholars situate students' perceptions of their confidence in their learning processes as a useful component to understanding metacognition (Anderson & Nashon, 2007; Thomas et al., 2008). For self-regulated learning, self-efficacy is central to motivation, and more specifically to students' expectations of their learning (Pintrich, Smith, Garcia, & McKeachie, 1991; Zimmerman & Moylan, 2009). While the definition of self-efficacy is similar within these two views, it is within the science education literature that the relationship between metacognition and self-efficacy is investigated more explicitly. It was this interpretation that I adopted within my research to explore the catalysts influencing students' metacognitive transformations.

This desire was motivated by the notion that students' ability to monitor, evaluate, and plan their learning (metacognition) is affected by whether the student perceives they can attain the science learning goal (self-efficacy) (Lindstrom & Sharma, 2011; Schraw et al., 2006; Thomas et al., 2008). Schraw et al. (2006) view metacognition as especially influential to science learning, but they also emphasize the need to increase students' self-efficacy to engage them in metacognitive processes. A student's level of self-efficacy can influence the extent to which they will persist with challenging tasks. Students high in self-efficacy and metacognition visualize success and tend to have higher academic achievements (Ambrose et al., 2010; Zimmerman & Moylan, 2009; Zusho, Pintrich, & Coppola, 2003), but if a learner does not know how to regulate their strategies, this fear of failure can decrease their self-efficacy. Bandura (1993) expressed that "those who doubt their efficacy visualize failure scenarios and dwell on many things that can go wrong. It is difficult to achieve much while fighting self-doubt" (p. 118).

Students low in self-efficacy often perform poorly because they lack effective strategies to achieve a task – or they lack the strategies altogether. The ability to regulate one's learning will be of little use if students are not able to apply strategies in the light of stressors and competing actions (Bandura, 1993; Muis, Franco, Ranellucci, & Crippen, 2010). This is particularly concerning for low-performing students who often need to mediate failure but lack the appropriate metacognitive strategies, confidence, or resources to do so. There is a need to assess and improve students' self-efficacy so they are confident in their ability to become metacognitively engaged learners.

2.5 Social Metacognition and Learning

Metacognitive research has been criticized for consistently viewing metacognition and learning from an individual standpoint (De Backer et al., 2012; Hurme et al., 2006; Iiskala, Vauras, & Lehtinen, 2004). More specifically, researchers are calling for more studies that explore how groups of students encompass metacognition in socially-shared learning contexts (De Backer et al., 2012; Hurme et al., 2006). Peer interactions can help to motivate students, while scaffolding from teachers helps to guide student learning and questioning. This is a relationship Brown and Palinscar (1989) refer to as to as reciprocal learning; learning as a conversation and not just a monologue. Even though individual or social learning "can be understood in its own right, understanding the interplay yields a richer and conceptually more satisfying picture" (Salomon & Perkins, 1998, p. 2). In addition, this type of modeling can help students to become more confident learners (De Backer et al., 2012; Schraw et al., 2006).

Teaching and learning is composed of interactions with and guidance from others, and as such is harnessed in, not separate from, individualized learning. These views of social aspects of learning and its relationship with metacognition have derived from theories of learning such as cognitive-constructivism (Piaget, 1962), social constructivism (Vygotsky, 1978), and situated cognition/learning (Brown & Palinscar, 1989; Lave & Wenger, 1991; Levine, Resnick, & Higgins, 1993). Taken together, these theories of learning reflect learning and knowledge, and more specifically metacognition, as socially *and* individually mediated. This combination presents the complexity of metacognition and learning: that learning is not fixed, but dynamic and continuously changing (Anderson & Nashon, 2007; Anderson et al., 2009; Thomas et al., 2008). Within science education, Taylor et al. (2002) indicate that a social constructivist perspective "recognizes science as a social construction and regards what is known already as a foundation for the learning of science. What individuals know, feel, and value is a critical part of what they will come to know about science" (p. x); knowing is both the construction of knowledge and the participation within a specific discourse community. As such, learning exists within, and can be enhanced through, collaborative and cooperative learning experiences (Kalman, 2007; Kalman & Milner-Bolotin, 2013; Lai, 2011).

Although each had their own agenda, educational scholars including Piaget, Vygotsky, & Dewey all emphasized the need for guided learning to enhance developmental change in learners (Brown & Palinscar, 1989; Salomon & Perkins, 1998). Student-to-student and teacher-to-student interactions are considered useful for enhanced conceptual understanding (Ambrose et al., 2010; Milner-Bolotin, Fisher, & MacDonald, 2013), but their rewards are often neglected in the theoretical literature. Brown and Palinscar (1989) discuss the minor role that social agents play in developmental psychologists' notion of learning. Even Piaget, whose work focused primarily on the actions of the individual learner, acknowledged that social interactions play an integral role in student development, but that these interactions and their impact on learning are too often ignored (Brown & Palinscar, 1989). Salomon and Perkins (1998) echo this perception and state that "'individual' learning is rarely truly individual; it almost always entails some social mediation, even if not immediately apparent" (p. 2). Thus, we cannot decontextualize learning from social environments.

2.6 Metacognitive Development

As expressed by Thomas (1999), we must "peel away the contextual layers that are associated with student change and provide readers with a view of student change that incorporates individual and social contextual factors" (p. 91). This change or shift in students' approaches to learning has been explored more longitudinally within the framework of metacognitive development (Baird, 1990; Case & Gunstone, 2002; Gunstone, 1994). Within this framework, changes in students' approaches to learning over time are considered as evidence for metacognitive development (Case & Gunstone, 2006; Gunstone, 1994). Empirical and theoretical work by Case and Gunstone (2002, 2006) explored how students' conceptions, organization, self-evaluation, and personal views of learning shifted over the course of a semester or school year (6-month and 10-month period) and, ultimately, how this manifested in their metacognitive development. This work highlighted the complexity of assessing students' metacognitive development and the important role that metacognitive knowledge and regulation in conjunction with non-cognitive issues play within students' development. While the goal of such research was to examine students' metacognitive development, Case and Gunstone (2002, 2006) acknowledged the context within which the learning and research took place as a critical player in students' development; that "metacognitive training is recognized to be intimately bound up in issues of content and context" (Case & Gunstone, 2002, p. 461)

Investigating students' learning strategies and recording their justifications for using and changing these strategies offer insight into how students' metacognitive dimensions are similar or different within a given period (Case & Gunstone, 2002, 2006; Thomas, 1999; Veenman, 2012). This development piece is useful for understanding how students will change as a learner. With respect to undergraduate students, Laurillard (2002) presents the idea of "learning as a change as a person" and that "the fact that these learners are capable of changing as a person through academic study makes the ideal of 'lifelong learning' seem at least plausible" (p. 39).

2.7 Metacognition (and Self-Efficacy) in the Classroom

Although examining the theoretical background of constructs related to learning is of necessity in educational research, Hacker (1998) emphasized the importance of also considering the practical and educational applications of metacognition, i.e. what role does metacognition play in the classroom and how can we help teachers to promote metacognitive awareness and development? The educational aspect of metacognition focuses more on how we can assist the development of metacognition along with describing and explaining it (Flavell, 1979).

Flavell (1987) mentions that, at a young age, children see value in their learning and are active participants in playing, exploring, and questioning. However I question whether, after many years of formal education, students, specifically undergraduate science students, see themselves as active cognitive agents, or as pawns in the game of a complex, demanding curriculum. Moreover, do they have the confidence and support to engage metacognitively with science learning? White and Frederiksen (1998) aim to create science curriculum that counteracts:

> the view that science is an abstract and difficult discipline that is accessible only to an elite subset of the population – namely, to high-achieving students…who, it is argued, are the only ones capable of the abstract, complex reasoning processes needed to learn and do science. (p. 5)

Many students, especially low-performing undergraduate students, struggle with developing an awareness of both their learning and the usefulness of their study strategies (Ambrose et al., 2010; Deslauriers, Harris, Lane, & Wieman, 2012; Kolencik & Hillwig, 2011; Seymour & Hewitt, 1997). Students are often ignorant of when and why they need help and are unable to differentiate what they know and do not know; a gap in their metacognitive knowledge (Tobias & Everson, 2002). Students are often aware that a strategy or approach is ineffective, and yet they “cannot break their fixation on this approach to develop a more worthwhile plan for solution” (Davidson & Sternberg, 1998, p. 58). If students perceive a strategy as requiring too much time/effort, they are more likely to revert to low-level study strategies (Quintana et al., 2005; Winne & Nesbit, 2009). This is further exaggerated in science where students perceive learning the content of science as taking primacy over the development of their metacognition (Thomas, 2012). For many undergraduate students, the learning of content is what equates to high grades and the strategies one develops and applies are secondary (Pressley, Van Etten, Yokoi, Freebern, & Van Meter, 1998). Although the provision of strategies, scaffolds, and advice are needed to develop and enhance students' metacognition, we must also prepare students for receiving and using the feedback from these resources.

Thomas (2012) commented that classrooms often lack the psychosocial attributes for developing and enhancing metacognition and self-efficacy, and that memorization and low-order thinking are often emphasized. Science teachers often challenge students' conceptual understanding, but also need to challenge students' beliefs and conceptions of how they go about learning science (Gunstone, 1994). Some science educators recommend reducing instructional time on learning scientific material focusing instead on the procedural, expert-like understanding of science (Ambrose et al., 2010; Schraw et al., 2006; Wieman, 2012). Experts in a given field have a firm grounding in the knowledge of the discipline, can retrieve and apply this knowledge, and can monitor their own thinking (metacognition) (Bransford, Brown, & Cocking, 1999; Wieman, 2007).

Wieman (2007) expresses that:

> Students are not learning the scientific concepts that enable experts to organize and apply the information of the discipline, nor are they being helped to develop either the mental organizational structure that facilitates the retrieval and application of that knowledge or the capacity for metacognition. So it makes perfect sense that they are not learning to think

> like experts, even though they are passing science courses by memorizing facts and problem-solving recipes. (p. 12)

This statement emphasizes the necessity for science curriculum and pedagogy that not only encourages students to think like experts, but assists students in becoming more metacognitive about their learning.

Although teachers are valuable to enhancing metacognition, few have been exposed to metacognition or even know what metacognition is (Georghiades, 2004; Thomas, 2012). There appears to be a lack of explicit conversation about metacognition, its relationships with self-efficacy, and its value in engaging students as active participants in their own learning. Metacognition is often embedded implicitly in classroom activities, however there is a need to make it more explicit.

Veenman (2012) and Thomas (2012) both present fundamental characteristics that can help to facilitate metacognition within the classroom. Veenman (2012) advocates for: 1) metacognition to be embedded in context with the task at hand; 2) students to be explicitly informed of the benefits of metacognitive strategies; and 3) instruction and training to be longitudinal to allow for metacognitive development (p. 32). In comparison, and in addition to Veenman, Thomas (2012) describes the need for a metacognitively-oriented classroom to include:

- Student-student discourse and student-teacher discourse about learning and processes that enable effective learning.
- Students critiquing the activities they engage in and to have a choice in their involvement with these activities.
- Students receiving encouragement and support by the teacher to improve their learning.
- High levels of emotional support and trust between the teacher and the students.

These guidelines reveal that within a metacognitively-oriented science classroom, there exists a reciprocal relationship between the teachers and the students. The teachers assist the students' enhancement of metacognition and self-efficacy through encouragement and support that is both academic and emotional. Ideally, with this support, students can become critical learners and begin to see the value and presence of collaboration in learning.

Adding metacognitive scaffolding within the classroom is particular helpful for low-performing students or for courses where the material is new for students (Brahmia & Etkina, 2001; DeHaan, 2005; Deslauriers et al., 2012). Barak (2011) discussed Dewey's notion of reflective practice, which encourages learners to thoughtfully reflect on how they have applied their knowledge and strategies to a particular learning task. Moreover, this process is practiced repeatedly and the learner is supported/coached by professionals in the discipline. White and Frederiksen (1998) used metacognitive scaffolding to help students become more reflective and confident about their learning processes. More specifically, the model they used asked students to reflect on the limitations, deficiencies, and affordances of their learning processes. They found that students' articulation of their learning processes not only improve their metacognitive abilities, but engages them more actively in their learning.

2.8 Paradigms, Epistemologies, and Ontologies in Metacognitive Research

In addition to the conceptualization of metacognition within undergraduate science reforms, we must also consider how metacognition is researched within science education. Anderson et al. (2009) express that "approaches employed by those who investigate metacognition can be understood as a function of the research paradigm with which they are aligned and their definition of metacognition" (p. 182). Metacognition and self-efficacy research has been conducted within two often contradicting paradigms:

positivist-decontextualist and/or empirical-analytic; and relativist-contextualist and/or constructivist-interpretivist (Anderson et al., 2009; Levin & Wagner, 2009; Teddlie & Tashakkori, 2009). The former paradigm relies more heavily on quantitative, evidence-based practices that view "students' responses [to questionnaires] and conceptions as right or wrong, giving little interpretation or consideration to the context" (Levin & Wagner, 2009, p. 214). This paradigm often attempts to simplify learning by trying to eliminate extraneous factors and making an artificial or controlled environment for analysis. Within this paradigm, metacognition is viewed as fixed, and is researched within experimental and statistical frames of cause and effect. Ontologically, this paradigm relies on an objective reality, and epistemologically, the researcher and the researched are considered independent entities (Sale, Lohfeld, & Brazil, 2002; Tashakkori & Teddlie, 1998; Treagust et al., 2014). Quantitative methods and positivist-decontextualist paradigms are the most commonly used approaches in (undergraduate) science education research. However in recent years, they have been combined with qualitative paradigms/methods to offer a more contextual understanding of student learning and metacognition (Levin & Wagner, 2009).

The relativist-contextualist and constructivist-interpretivist paradigms embrace the dynamics of educational research and, more specifically, metacognitive research. This paradigm is often qualitative and interpretivist in nature and acknowledges the complexities of learning and learning environments (Creswell, 2009; Mertens, 2010; Treagust et al., 2014). Interpretive work aims to develop meaning from understanding through the exploration of the experiences and reflections of not only the research participants, but the researchers as well (Bogdan & Biklen, 1998; Creswell, 2009, 2013). The research within this paradigm often triangulates data from more than one source in order to enhance the trustworthiness of the data. And while data collection using qualitative methods is often described as taking considerably more time and effort to analyze and interpret than using quantitative methods, the results of the research offer a more in-depth exploration of the contextual complexities of science learning (Levin & Wagner, 2009; Tashakkori & Teddlie, 1998; Teddlie & Tashakkori, 2009).

To gain a better understanding of the relationship between researchers' paradigmatic frameworks, the methods they use, and their research questions, I returned to the literature and examined various studies exploring metacognition, self-efficacy, and self-regulated learning (summarized in Appendix A). This process was extremely useful for pinpointing the methodological similarities and differences existing among the studies. Treagust et al. (2014) indicate that "by describing how different paradigms play out in the science education research field, we attempt to reflect on our own research practices and facilitate a dialogue across paradigms among science education researchers" (p. 4).

Within the literature, few scholars explicitly present their epistemological and ontological positions/assumptions about metacognition, self-efficacy, and learning, and most studies rely on survey methods research for analysis. However, in their research exploring metacognition and self-efficacy in science education settings Anderson et al. (2009), Nashon and Anderson (2004), Nielsen et al. (2009), Thomas and Anderson (2012), and Thomas (2003) view learning, metacognition, and self-efficacy as holistic, dynamic, and influenced by both individual, social, and cultural factors. These research studies are embedded within relativist-contextualist and constructivist-interpretivist paradigms that stem from theories of social constructivism, constructivism, and situated learning which view learning as being constructed both individually and socially (Anderson et al., 2009; Levin & Wagner, 2009; Mertens, 2010; Vygotsky, 1978). This explicit grounding assists the reader to draw a more informed view/opinion of how, why, and by whom the research was conducted.

2.9 Methods for Measuring Metacognition

One of the main criticisms of research exploring metacognition and self-efficacy is that these are difficult constructs to observe directly. Their measurement relies primarily on retrospective self-reports from individuals who are often not aware of or who don't know how to assess their perceptions of or confidence in their learning (Akturk & Sahin, 2011; Georghiades, 2004). There is also the concern of whether or not students are responding honestly, and if they are influenced by what they think the teacher and/or researcher wants to know (Tobias & Everson, 2002, 2009). Despite the several methods and approaches used to address these concerns, arguments persist regarding the advantages and disadvantages of various methods to assess metacognition and self-efficacy (Anderson et al., 2009). Georghiades (2004) criticized that:

> the lack of consensus in the literature regarding how to recognize and measure metacognition in action, along with the absence of reliable tools for this purpose, means that any attempts are bound to be problematic and heavily dependent upon the subjective judgment of the researchers (p. 374).

This statement, if taken too literally by a pessimistic or discouraged individual, may cause them to abandon their work in metacognition altogether. Luckily, Georghiades (2004) brought awareness to the need for more metacognitive research within science education to help alleviate some of the challenges with measurement and interpretation.

A review of the literature reveals several data collection methods that have been used to capture prior, retrospective, and "real-time" accounts of students' metacognition and self-efficacy in (science) education research. As described in **Table 3**, each method has its own set of advantages and disadvantages or concerns[1].

Overall, questionnaires are the most frequently used method to assess metacognition and self-efficacy, and are described as an easier tool to administer and interpret than qualitative methods (Akturk & Sahin, 2011; Teddlie & Tashakkori, 2009). Despite their pervasive use, questionnaires are criticized as a static, positivistic type of assessment that lacks an in-depth, contextualized, and personalized look into the experiences of students. Qualitative methods, on the other hand, are time-consuming and costly, but advantageous in that they offer the ability for study participants to expand on their experiences and for researchers to probe particular issues or concerns (Teddlie & Tashakkori, 2009). Gonny Schellings and Van Hout-Wolters (2011) stated that, although the aforementioned methods have several distinct differences, each of them strives to gain insight into how students' metacognition and self-efficacy influence their learning. While the argument for or against particular methods is valuable to acknowledge, the decision to choose a particular method should not be due to ease of administration or analysis, but should reflect the research question under investigation. It is particularly important for researchers to consider what method(s) best support their research goals, questions, resources, and paradigmatic stances.

While questionnaires and surveys are most often considered quantitative, positivistic tools, the way in which they are used and analyzed can fall under a constructivist or interpretivist lens. For instance, Anderson and Nashon (2007) and

[1] I was inclined to use the term concern instead of disadvantage to describe the limitations of a method because "disadvantages", within the literature, appears to carry a negative connotation whereas "concern" better suggests the issues, limitations, and/or

Table 3

Summary of the advantages and disadvantages/concerns of the methods used for the analysis of metacognition and self-efficacy in (science) education

Method	References	Notes	Advantages	Disadvantages/Concerns
Survey, Questionnaire	Akturk and Sahin (2011); Cooper and Sandi-Urena (2009); Duncan and McKeachie (2005); (2010); G. Schellings (2011); Gonny Schellings and Van Hout-Wolters (2011); Schraw and Dennison (1994); Thomas (2003)	• Most common for retrospective	• More students in one go • Easier administration and scoring/analysis • Explore similarities/differences between dimensions of metacognition	• Based on self-report • May not provide an in-depth analysis of students' beliefs/experiences • Lack of specificity and/or contextualization
Interviews	Akturk and Sahin (2011); Anderson and Nashon (2007); Mertens (2010); Rompayom et al. (2010); Schraw and Dennison (1994)	• Sharing of experiences • Dominant strategy in data collection	• Provide power for students/teachers to expand on their answers • Complement other methods • Full range and depth of information	• Time consuming and costly • Cannot be implemented in classroom • Students may not be able to verbalize their answers appropriately
Focus Groups	Allan and Clarke (2007); Bogdan and Biklen (1998); Mertens (2010); Peters and Kitsantas (2009); Rompayom et al. (2010)	• Creating a dynamic group dialogue	• Validate findings from other methods • Collecting common experiences • Depth and range in less time	• Need a good facilitator • Difficult to schedule individuals • Time consuming and costly
Think-Alouds	Akturk and Sahin (2011); Boekaerts and Corno (2005); Rompayom et al. (2010); Schraw and Dennison (1994); Tobias and Everson (2002)	• Student reports thoughts, feelings, & strategies while solving a problem	• "Real-time" data (not retrospective) • Provide insight into students' use of particular strategies when completing a task	• Not functional in classroom • Students may not be able to verbalize their thinking patterns appropriately
Observations, Field Notes	Akturk and Sahin (2011); Anderson and Nashon (2007)	• Often collected by the researcher	• Capture ongoing rather than recalled actions	• Difficulty with objectively observing actions.
Written reflections	Allan and Clarke (2007); Bogdan and Biklen (1998); Heikkila and Lonka (2006); Kalman (2007)	• Student appraisal of their personal development/issues	• Confronting personal opinions, prejudices, and/or experiences	• Students can become fatigued • Participants may not know how to reflect effectively
Stimulated recall/deliberations	Anderson and Nashon (2007); Anderson et al. (2009); Boekaerts and Corno (2005)	• Students watch/evaluate their progress on a task	• Basis for rich discussion and context for exploring metacognition	• The scenario researchers choose to analyze may not parallel that of students' selection
Video Recordings	Anderson and Nashon (2007)	• Students videotaped during a task	• Students/researchers can review student accounts/progress	• Students may act differently if they know they are being observed

Nielsen et al. (2009) positioned themselves and their work within a constructivist-interpretivist paradigm, and yet they collected parts of their data though the use of quantitative methods. They used this quantitative data to make meaning of students' experiences and to understand their perceptions of and use of metacognitive strategies for learning science. Ergo the method itself does not define the paradigm from which the researcher is situated; what is most important is what overarching paradigms affect the researcher's use of particular methods and their interpretation of the data.

2.10 Literature Review Summary

This synthesis of the literature has revealed the complexities associated with curricular and pedagogical reforms in undergraduate science education. While I agree that the shift towards more inclusive, learner-centered undergraduate science courses is highly beneficial, we cannot ignore that these shifts take considerable time, resources, and individuals for successful implementation (Henderson et al., 2010; Laurillard, 2002; Wieman, 2012). In particular, administrators, faculty, and students alike are critical stakeholders within these desired environments (DeHaan, 2005; Hubball & Gold, 2007; Meredith & Redish, 2013). The implementation of learner-centered curricula and pedagogies are often new for both faculty and students. As such, there is a need to support these individuals in order to reduce resistance (Baird & Northfield, 1991; Laurillard, 2002; Redish & Hammer, 2009; Taylor et al., 2002) and it is critical for these reforms to be assessed at the course, department, and institutional level (Henderson et al., 2010; Meredith & Redish, 2013; Wieman, 2007).

Within these reforms it is also essential to include metacognition as an explicit, rather than an implicit, component of curriculum and pedagogy (Redish & Hammer, 2009; Thomas, 2012). Unfortunately, in many circumstances, metacognition, or the desire to engage students in how they are learning and not only in what they are learning, is overshadowed by preconceived beliefs about learning or by an emphasis on grades and/or performance (Pressley et al., 1998; Thomas, 2012; Zohar & Barzilai, 2013). As such, there is a need to engage students and instructors in a conversation about the learning of science; to empower students to become metacognitive, confident learners. Brown and Palinscar (1989) comment that "change is more likely when one is required to explain, elaborate, or defend one's position to others, as well as to oneself; striving for an explanation often makes a learner integrate and elaborate knowledge in new ways" (p. 395).

While there is a growing body of research about metacognition and self-efficacy in science education (Thomas, 2012; Veenman, 2012; Zohar & Barzilai, 2013), there is a need for studies that explore undergraduate science students' metacognitive development in learner-centered classrooms (Case & Gunstone, 2006; Tanner, 2012). More specifically, there exists a place for research that provides a holistic description and analysis of the possible events, activities, and/or interactions that can enhance and/or impede students' metacognition and self-efficacy in an undergraduate science course. Researchers exploring metacognition and self-efficacy suggest studies that listen, observe, analyze, and interpret how students plan, monitor, and evaluate their study strategies (Pressley et al., 1998; Tobias & Everson, 2002).

The above critique of the various studies of metacognition not only informed the design of my own study but also revealed the strong connections between the researchers, the paradigm they associate with, and the methods they use. Figure 2 is a description of the relationship I have conceptualized and/or visualized with respect to how research is designed and conducted.

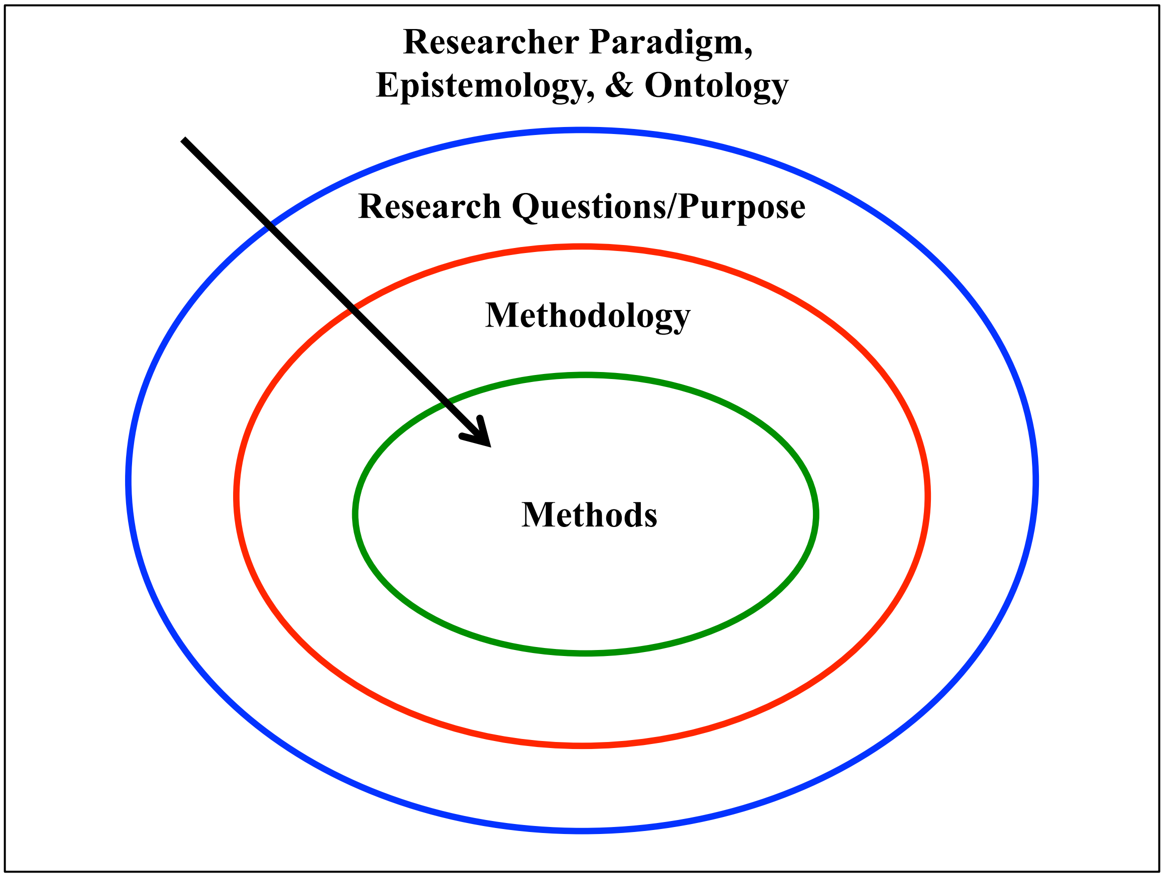

Figure 2 A visualization of the research process.

First and foremost, I conceptualize the paradigm, epistemology, and ontology of the researcher as the most critical factors influencing the development, dissemination, and interpretation of the research. The research questions and purposes posed by a positivist-decontextualist and a constructivist-interpretivist exist within very different paradigmatic camps and are extremely influential to the methodological processes of analysis and interpretation. Although quantitative and qualitative methods have been linked to positivist and interpretivist paradigms respectively, the methods should actually reflect the research question(s) being posed (Braun & Clarke, 2006; Treagust et al., 2014). It is the interpretation and conceptualization of these methods that reflect the paradigmatic position of the researcher, not the categorization of something as quantitative or qualitative. That is, research questions and the paradigmatic stance of the researcher are key components in the design and interpretation of a given study. This review allowed me to better situate and justify my own assumptions and biases and the methodology and methods that would best answer the research questions driving this study (see Chapter 3).

2.11 Theoretical Framework

The theoretical framework for this research emerged from my review and synthesis of the literature about metacognition and self-efficacy in (undergraduate science) education. As such, this study is grounded primarily in theory and research on metacognition (Anderson & Nashon, 2007; Flavell, 1976, 1979; Flavell et al., 2002; Thomas et al., 2008), metacognitive development (Baird, 1990; Case & Gunstone, 2002, 2006), and social (meta)cognition (De Backer et al., 2012; Hurme et al., 2006; Levin & Wagner, 2009). The foundational work of Flavell (1976, 1979, 1987) about metacognition as knowledge, experiences, and regulation provided a means for pinpointing and discussing students' metacognition within this research. This idea of metacognition was further supported by the five dimensions of metacognition as presented by Thomas et al. (2008) (i.e. constructivist connectivity; monitoring, evaluation, and planning; learning risks awareness; control of concentration; and self-efficacy). These conceptualizations of metacognition offered a contextualized view of metacognition and the need for students to be aware of themselves as learners, to regulate their strategies, and to acknowledge the role of self-efficacy in their learning.

The development or transformation of students' metacognition (Baird, 1990; Case & Gunstone, 2002, 2006; Gunstone, 1994) and the impact of social contexts (De Backer et al., 2012; Hurme et al., 2006; Levin & Wagner, 2009) also played important roles in the conceptualization of metacognition within this study. Not only was it important to consider how students' metacognition changed (or did not change) over time, it was also critical to understand how it manifested within and through social environments and interactions. I thus viewed learning and metacognition as conceptualized and influenced through “socially mediated knowledge construction” (Taylor et al., 2002, p. 6). As per Laurillard (2002),

> Students are not simply learners of an academic subject; they are social beings. Like everyone else, they respond to the social, political and organisational context around them, and this directly affects what they do in their day to day work. (p. 199)

Finally, I did not decontextualize learning from the social, but recognized the complex relationship between metacognition and broader constructs of learning within a contextual, social environment. The catalysts for students’ metacognitive transformations could be due to personal, motivational, social, and historical contextual factors (Thomas, 1999), which led me to embrace the complexity of learning and to acknowledge the presence that non-cognitive issues can have on students’ metacognitive development (Case & Gunstone, 2002). I also acknowledged how additional factors such as motivation, emotional state, and professional goals, could influence undergraduate science student learning (Case & Gunstone, 2006; Zimmerman & Moylan, 2009).

Metacognition and its relationship with learning are complex and embedded within the social, cultural, and political aspects of students’ learning experiences within the science classroom. Taking on this perspective provided an expanded and more informed view of students’ metacognitive transformations. The use of these frameworks helped me to better conceptualize metacognition, its social and developmental aspects, and its role in students’ science learning.

Chapter 3: Methodology

The literature review in Chapter 2 provided an initial introduction to the methodologies and methods used most often to explore metacognition in science education. This chapter will speak more specifically to the methodological underpinnings of this study. The first part of this chapter will present the research questions and describe the paradigms, epistemologies, and ontologies influencing the research design and process. The specific case under investigation, data collection methods and analysis, and the ethical considerations and limitations to the study will also be discussed.

3.1 Framework and Research Questions for this Research

Methodology has been defined as the logic and theoretical perspective embedded within a research project, whereas methods are the specific techniques used for investigation and assessment (Bogdan & Biklen, 1998). Anderson et al. (2009) indicated that methodology is not only composed of the methods one uses to conduct research, but encompasses the "research design, including its foundations, assumptions, limitations, and characteristic procedures and outcomes" (p. 182). Boekaerts and Corno (2005) echoed this description and emphasized the need for researchers to be more willing to discuss how conceptual models, assessment tools, and research design are conceptualized within a given research project.

This study used an interpretive (Creswell, 2009; Erickson, 1998; Green et al., 1989; Mertens, 1998; Teddlie & Tashakkori, 2009; Treagust et al., 2014) case study approach (Merriam, 1988; Stake, 1995; Yin, 2003) framed within a constructivist paradigm (Anderson & Nashon, 2007; Anderson et al., 2009; Lave & Wenger, 1991; Mertens, 1998; Thomas & Anderson, 2012), drawing largely on phenomenological and ethnographic methods (Adams & van Manen, 2008; Creswell, 2013; Mertens, 1998; Østergaard, Dahlin, & Hugo, 2008) to explore the following research questions:

1. *What are the catalysts for metacognitive transformation during one semester of an introductory organic chemistry course for biological science majors?*
2. *What aspects/characteristics of the catalysts do students perceive as most influential to their metacognitive transformations?*
3. *To what extent do social dimensions influence the metacognitive transformations of students in an introductory organic chemistry course?*
4. *What do students perceive as the barriers and enhancers to their metacognitive transformations and how do these barriers and enhancers manifest during Chemistry study discourse?*

The research was framed around a constructivist-interpretivist paradigm (Anderson et al., 2009; Mertens, 1998; Nielsen et al., 2009) that stems from ideas of social constructivism, constructivism, and situated learning which view learning as being constructed both individually and socially (Anderson et al., 2009; Levine et al., 1993; Mertens, 1998, 2010; Vygotsky, 1978). This view acknowledges the nature of both the learner and the complex context within which the learning occurs (Creswell, 2009; Nielsen et al., 2009; Treagust et al., 2014). Similar to Anderson and Nashon (2007), I perceive metacognition as fluid in any given context and learning as a "dynamic process developed through the experiences that are interpreted in the light of the learners' prior knowledge, their attitudes, and personal backgrounds" (p. 300). However, along with taking this stance, I also appreciate that students' personal conceptions of how they learn both limit and enhance their metacognitive knowledge and processes.

Ontologically, I perceive reality as socially constructed and epistemologically, I perceive myself (the researcher) and the students (the participants) as "interlocked in an interactive process; each influences the other" (Mertens, 1998, p. 13). Within the realm of constructivism and social constructivism research, Creswell (2009) indicates that researchers must recognize that,

> Their own backgrounds shape their interpretation, and they position themselves in the research to acknowledge how their interpretation flows from their personal, cultural, and historical experiences. The researcher's intent is to make sense of (or interpret) the meanings others have about the world (p. 8).

Within this lens and in my research, students were the access points to understanding metacognition and self-efficacy more holistically while I acted as the primary medium for interpretation. I was cognizant of how my own behaviours, assumptions, and experiences influenced the research project and its findings (Merriam, 1988), and as a researcher, I "do not claim that [my] knowledge claim is a complete or the right one but that it is a sensible interpretation of the situation" (Treagust et al., 2014, p. 7)

In order to provide a complex, in-depth analysis of the catalysts influencing students' metacognitive transformations within an introductory organic chemistry course at UBC, I adopted a case study approach employing both quantitative and qualitative methods (Merriam, 1988; Stake, 1995, 2005; Yin, 2003). Case study is a research approach stemming from a desire to understand complex "bounded" social phenomena through a holistic and meaningful representation of real-life events (Stake, 1995; Yin, 2009). The strength of this approach is its ability to gather and triangulate a variety of rich data collected via both quantitative and qualitative methods (Yin, 2009). While some scholars note that the use of and triangulation of quantitative and qualitative methods in a research design are incompatible (Sale et al., 2002), others disregard this paradigmatic dichotomy and, as mentioned previously, emphasize that particular aspects and methods within research “appear to be logically connected to the [researcher’s] paradigm of choice” (Merriam, 1988, p. 3).

A case is a bounded system (like a program, institution, person, or process) chosen based on its uniqueness and commonality alike (Merriam, 1988; Stake, 1995; Yin, 2009); while the case may have similarities with other circumstances, something about the case makes it unique and worth investigation. Within this framework, it is difficult to separate the system or phenomena from its specific context. As Stake (1997) conceptualizes, a case is,

> Something deemed worthy of close watch. It has character, it has a totality, it has boundaries. It is not something we want to represent by a score… It is a complex, dynamic system. We want to understand its complexity. (p. 256)

The case.

This study explored the catalysts that students perceived as influential to their metacognitive transformations in an introductory, second-year organic chemistry course (CHEM 200) for biological science majors at the University of British Columbia Vancouver campus. This course took place during the Winter I semester (September-December) of 2013 and was comprised of five sections taught by four different instructors. The case for this research was bounded within two sections (comprising about 240 students per section) taught by the same instructor. The instructor had taught the course for nine years and, in response to the observed struggle of students with adopting appropriate strategies for learning undergraduate organic chemistry, has been adapting the course curriculum and pedagogy to help students engage with, confront, and evaluate their learning.

This particular case was chosen for both its commonalities and differences with other sections of this course, as well as with the overall teaching and learning of introductory organic chemistry within science education. CHEM 200 at UBC has the reputation of a difficult second-year course, and this reputation holds within the literature as well (Grove & Bretz, 2012; Lynch & Trujillo, 2011). What made this case unique, however, was the instructor. She had received several teaching awards and excellent teaching evaluations from her students and had adopted evidence-based teaching practices to enhance student learning. Despite this, a high number of students still struggled with learning the course content and completing the course successfully. The instructor was concerned that her efforts were not resulting in significant differences in student learning. At the time of the study, she and I had been colleagues for the past five years and as such she was willing to allow me to explore the catalysts students perceived as most influential to their metacognitive transformations in CHEM 200.

I chose an interpretive (Merriam, 1988; Yin, 2009; Zohar & Barzilai, 2013) case study for this research in order to conduct a "naturalistic study of teaching and learning in one setting" (Stake, 1997, p. 257) and to provide a more holistic picture of student experiences in CHEM 200 with this particular instructor. While the findings of this study in their entirety may not be generalizable to the other course sections or to other institutions, the data analysis aimed to offer analytical, not statistical, generalizations (Yin, 2009) that could be related to, or considered within, the teaching and learning of introductory undergraduate organic chemistry at UBC and beyond.

CHEM 200 at UBC.

CHEM 200 is a required second year introductory organic chemistry for biological sciences students at UBC and is a pre-requisite for their second year biochemistry course. Roughly 1,100 students were registered within five sections for the Winter I semester of the 2013/2014 school year. At UBC, semesters are 13-weeks long followed by a three-week final examination period. CHEM 200 students were in-class three hours per week.

The course had a teaching team of four instructors with one of the instructors teaching two sections (which is the population of interest for this study).

Previous iterations of this course had been taught primarily via traditional lecture-based pedagogy that periodically used Peer Instruction (Mazur, 1997) to engage students in discussion about the content and their learning. Feedback and assessment from previous years revealed that few students would complete practice problems outside of the classroom leading many students to struggle when it came to performing on examinations. In response to this concern, in the year the study took place, the teaching team adopted notions of a “flipped classroom” approach for instruction (as illustrated in Figure 3). Estes, Ingram, and Liu (2014) describe the flipped classroom as an approach for “combining collaborative coursework with online materials and activities to help instructors understand student needs, offer timely feedback, and plan lessons responsive to those needs”. While several scholars have offered many flavours of what is meant by “flipped”, the central idea is that students’ are exposed to the bulk of the course content outside of lecture (via technological means such as recorded lecture) and that in class, students apply the material they have learned through complex problem-solving and peer instruction (Jensen, Kummer, & Godoy, 2015). As such, the student is responsible for attaining the content outside of class, and the instructor facilitates the application of this content within class.

In CHEM 200, prior to coming to class, students watched a 10-20 minute video on a particular topic and completed an accompanying quiz. Within the classroom students worked with their peers on worksheets (designed by the instructors) while the instructor answered individual/group questions and modeled how to solve the problems with the whole class. After each lecture, students were encouraged to complete the optional problem set assignments and to discuss their questions or concerns with their peers and instructor.

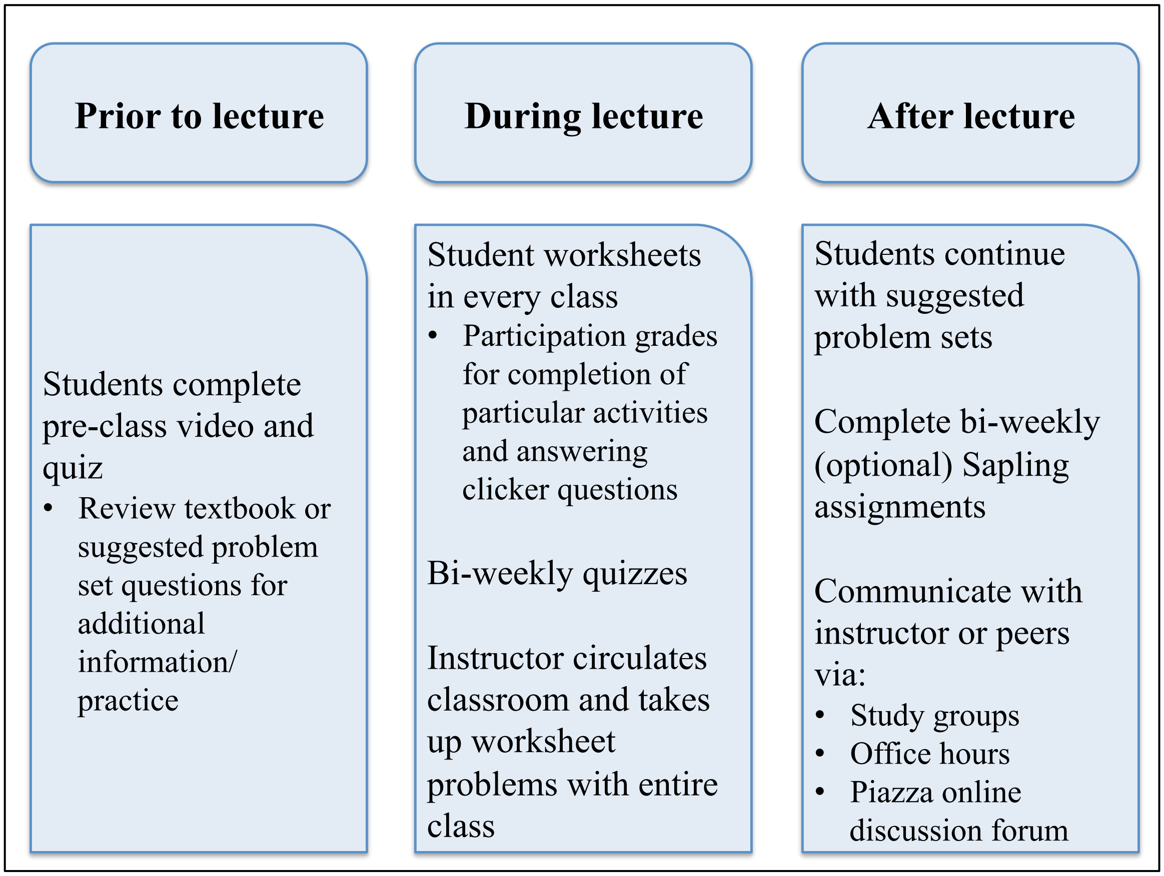

Figure 3 The flipped classroom structure for CHEM 200.

Students' final grades were determined by one of the two grading schemes described in Table 4.

Table 4

Grading scheme options for students in CHEM 200

Assessment Method	Percentage of Overall Grade	
	Grading Scheme 1	Grading Scheme 2
Pre-class video quiz	5%	5%
In-class participation	5%	5%
In-class quizzes	5%	5%
Sapling learning homework	10%	-
First Midterm exam	15%	17%
Second Midterm exam	15%	17%
Final Examination	45%	51%

The difference between these two grading schemes was whether or not the Sapling, the online learning homework, was included in the final grade. The instructor encouraged students to complete the Sapling assignments and indicated that students who complete it tend to receive higher grades in the course. However, completing the Sapling assignments was not required. At the end of the term, the instructor computed students' final grade using both schemes and then selected the higher of the two.

Student participants, recruitment, and confidentiality.

Students in two sections (n_1=243 and n_2=234) of CHEM 200 were the population of interest for this study. This selection was based on the instructor who was teaching the two sections. The majority of students (80.3%) within these sections were in their second year of a biological sciences degree with 11.3% of students in their first year and 8.4% in the third year or higher.

Prior to conducting this study, I obtained approval from the UBC Behavioural Research Ethics Board (Certificate #H13-01787). For student recruitment, on the third day of class the instructor introduced me to the students and explained my role as a graduate student. Each student had been provided with a consent form (Appendix B) at the beginning of the class along with their daily worksheet. I then gave a brief presentation on the goals of the research and the instructor endorsed that I would be collecting survey data, observations, and feedback from the students to gain perspectives on their experiences in the course. I continued to describe the goals of the course and the various types of data I would be collecting throughout the semester. The instructor and I encouraged students to participate and indicated that if they had any questions or concerns, they could contact me directly. I emphasized student confidentiality and that the instructor would not have access to any identifiable student data. I then asked students to complete the consent form if they were interested in participating and to place the completed forms in collection boxes scattered throughout the lecture hall or to hand it in at a later date if they wanted to read the consent form in more depth. The consent form was also posted on the course website for any students who were absent from class.

Overall, 288 out of 477 (60.4%) of the students in these two sections consented to having their information used as a part of this study. Roughly 58% and 42% of these students were registered in the first and the second section, respectively. 80.6% of those students were in their second year with 10.4% in their first year and 9% in third year or above.

Data collection methods.

This interpretive work drew largely on phenomenological and ethnographic methods (Adams & van Manen, 2008; Creswell, 2013; Mertens, 1998; Østergaard et al., 2008) that aimed to develop meaning from understanding through the exploration of the experiences and reflections of the students in CHEM 200. A case study approach often adopts phenomenological and ethnographic principles as the case "involves intensive and detailed study of one individual or of a group as an entity, through observation, self-reports, and any other means" (Mertens, 1998, p. 166). As a researcher I am both interested in exploring science students' lived experience (Adams & van Manen, 2008; Østergaard et al., 2008) and how they interact with or experience a particular context or culture (Creswell, 2013; Treagust et al., 2014).

Case studies typically draw on multiple data collection methods such as observations, interviews, documents, and visual material (Creswell, 2013; Merriam, 1988; Stake, 1995; Yin, 2009). Based on the research questions, and considering the limitations and affordances of the case itself, I chose a survey instrument, observations, a midterm feedback survey, and one-on-one student interviews for this study. The survey instrument could be easily administered during the class and provided a pre- and post-perception of students' dimensions of metacognition and self-efficacy (Anderson & Nashon, 2007; Thomas et al., 2008). The observational, written, and verbal methods, on the other hand, helped elucidate these metacognitive dimensions and provided a more contextual representation of students' experiences (Bogdan & Biklen, 1998; Creswell, 2013; Mertens, 1998). The data were triangulated to provide a more coherent picture of how and in what ways various catalysts and social dimensions of learning influenced students' metacognitive transformations. The following subsections provide a more detailed description and justification for the data collection methods used in this study.

Self-Efficacy and Metacognition Learning Instrument–Science (SEMLI-S).

The SEMLI-S (Thomas et al., 2008) was selected to provide a window into how students' dimensions of metacognition, both individually and as a group, changed over the course of the semester (Appendix C). It is a 30-item instrument that uses a 5-point Likert scale (1=Never or Almost Never; 2=Sometimes; 3=Half of the Time; 4=Frequently; and 5=Always or Almost Always) to assess student responses to how often they engage with particular metacognitive processes. As mentioned previously in Chapter 2 (page 23), the survey items are classified according to five metacognitive dimensions (Table 5).

Table 5

A summary of the five SEMLI-S metacognitive dimensions

Dimension	Number of survey items on SEMLI-S	Description	Sample survey item
Constructivist Connectivity	7	Explores whether students make connections between information and knowledge across science learning environments	I seek to connect the information in this course with what I already know.
Monitoring, Evaluation, and Planning	9	Explores important, traditional strategies for learning science	I stop from time to time to check my progress on a learning task.
Control of Concentration	3	Explores whether students control their level of concentration	I adjust my level of concentration to suit different science subjects.
Learning Risks Awareness	5	Explores students' awareness to situations that may interfere with their learning	I am aware of when I have learning difficulties.
Self-Efficacy	6	Explores students' confidence in being able to achieve learning/course objectives	I am confident I can do a good job on the assignments and tests in this class.

While survey methods have been criticized for being embedded within a fixed, decontextualized positivistic framework (Merriam, 1988; Tashakkori & Teddlie, 1998) within this study the data from the SEMLI-S acted as a "signpost" or "lens" to students' levels of metacognition. Thomas et al. (2008) expressed that,

> A multi-method approach is most appropriate for exploring students' learning processes and metacognition and even though the SEMLI-S is a statistically robust instrument, it does not attend to all aspects of science students' learning processes and metacognition. Therefore, it should be used with other methods to give credible and trustworthy assessments in relation to the nature and extent of students' metacognitive science learning orientations. (p. 17)

The SEMLI-S was administered in class at the beginning of the term (during the third class of the semester) and during the final week of the course (week 13). Paper copies of the SEMLI-S were distributed at the start of both classes with students being given 10-15 minutes to complete the form. Students then placed their completed (or incomplete) SEMLI-S in collection boxes that were placed around the lecture hall.

For this research study, students' responses to the SEMLI-S provided one interpretive measure for examining student learning. They were a piece of the puzzle for understanding the catalysts influencing student metacognition and learning in CHEM 200. These results were combined with additional verbal and written accounts of students learning in CHEM 200 to provide a more holistic picture of the student experience.

Classroom observations.

Teddlie and Tashakkori (2009) describe observational data collection as a strategy to record "units of interaction occurring in a defined social situation based on visual examination or inspection of that situation" (p. 218). Classroom observations were selected for this study to provide a "real-time" window into the possible catalytic events that triggered students' metacognitive transformations and that took into account how social interactions played out within the classroom. Observations were collected using the Classroom Observation Protocol for Undergraduate Science (COPUS) by Smith, Jones, Gilbert, and Wieman (2013) (Appendix C) which allowed for both closed-ended and open-ended observations (Teddlie & Tashakkori, 2009). The closed-ended observation piece included the COPUS rubric where I recorded what activities the students (listening, group work, asking a question, etc.) and the instructor (lecturing, roaming the class, answering questions, asking a clicker question, etc.) exhibited within a 2-minute segment in lecture. In addition to this structured observation I recorded open-ended observations during class time. Throughout the data collection process, I recorded reflective notes about each class and noted any similarities or differences from one lecture to the next.

Classroom observations occurred during every class in both sections during the 13 weeks of CHEM 200. I sat in various places in order to gain a better sense of whether students were engaging with the worksheets, and if they were working and staying on task. My presence was intended to be unobtrusive to students' engagement in the course and as such I usually sat on the outside of rows in the back, middle, or front of the class. Over the course of the semester I had some students recognize me and/or talk to me, but it was rare that any of them conversed or looked at me during lectures. While it may not have seemed my presence affected the students, I must acknowledge that my mere presence may have influenced their engagement with the lecture material. I addressed this concern by observing all of the lectures and by not focusing on individual students.

Midterm feedback survey.

A midterm feedback survey was administered online to all CHEM 200 students during the sixth week of the semester to offer students the opportunity to provide feedback and for the instructor to evaluate the progress of the course (Bain, 2004; Cohen, 1980). The instructor in this study added additional open- and closed-ended questions that addressed the usefulness of particular course resources and assessment, and students' perceived learning challenges. These additional questions related directly to the research questions (i.e. catalysts for metacognitive transformation) and were selected for analysis. The reflections provided another means for investigating students' perceptions of their metacognitive transformations and the catalysts influencing these transformations.

Three of the additional multiple-choice questions asked the students to indicate: whether they used a particular course resource ("yes" or "no"); the usefulness of this course resource ("not at all useful" to "very useful"); and the extent to which students engaged with the worksheets and their peers in class ("giving little effort and working alone" to "giving my best effort and working with my peers"). The first two survey questions helped to answer the first two research questions about catalysts to students' metacognitive transformations. The third survey question provided insight into the role that social interactions played within students' metacognitive transformations and learning.

The two open ended questions provided a window into: 1) students' perceived challenges to their learning; and 2) accounts of how students intended on improving their learning for the remainder of the semester. These questions were selected to offer a clearer picture of the catalysts for transformation than the closed-ended questions alone.

In comparison to the SEMLI-S that was used as a window into students' metacognitive dimensions, this survey provided a more contextualized perspective of students' experiences in CHEM 200 specifically. And again, while questionnaires or surveys only offer a snapshot in time of students' perceptions (Tobias & Everson, 2002), the triangulation with the other data allowed for a more coherent picture of the possible catalysts influencing students' metacognitive transformations in CHEM 200.

One-on-one interviews.

One-on-one interviews were conducted to collect a retrospective perspective of students' metacognitive transformations and the catalysts that triggered these transformations. Students' responses also revealed how social factors influenced their metacognition and learning. These interviews drew from phenomenological and ethnographic methods to attempt to provide insight into the individual's subjective experience (Merriam, 2002; Mertens, 1998). The student's subjective experience was at the centre of the inquiry, and as the researcher, I tried to understand how students positioned CHEM 200 within their own worldview.

To select interview participants I first contacted students who completed both the pre- and post-SEMLI-S in order to access students who could comment directly on their SEMLI-S scores. These targeted e-mails (Appendix B) resulted in only seven student responses so I gave a brief in-class presentation to both CHEM 200 sections in order to recruit more students. As a result of this, another 30 students e-mailed me about participating in an interview. Due to scheduling conflicts or drop out, 26 students in total completed the one-on-one interviews during the exam period and prior to their final examination.

The interviews began by asking students to reflect upon their experience over the course of the semester and how it affected their learning strategies. Throughout the interview I attempted to keep the questions open-ended so as not to "force respondents to fit their knowledge, experiences, and feelings into the researchers' categories" (Patton, 1990, p. 348). The interviews also followed what Patton (1990) refers to as a *general interview guide approach:* while specific questions and topics were decided in advance, the order and wording of the questions came in response to the natural progression of discussion present within the interview. This approach was selected in order to encourage more of a conversation between the student and myself, rather than strictly a question and answer interview. I also chose the questions (presented fully in Appendix C) and themes in advance to ensure that the interview did not get off topic but reflected questions that would help answer the research questions.

The interview included questions such as:

- If someone were to ask you what your experience has been like in CHEM 200, what would you tell them and why?
- What factors (and why) would you attribute as most influential to your learning?
- Did you make any changes to your approaches to learning over the course of the semester? What triggered this change (or lack of change)?

During the interview I also discussed with students their SEMLI-S and midterm survey responses. Students who had not completed the surveys were asked specific questions about the five SEMLI-S dimensions and how their approaches to learning changed over the course of the semester. We also talked about the change (or lack thereof) in their own midterm scores over the course of the semester. The interviews provided a personalized glimpse into the barriers and enhancers to metacognitive transformations and the possible patterns of metacognitive transformation among students.

Data analysis.

I adopted a holistic data analysis in order to provide a detailed description of the case and to understand the complexity of the case more clearly (Creswell, 2013; Stake, 1995; Yin, 2009). In order to accommodate the vast amount of data collected in this study, I examined the data from each method individually and then triangulated and synthesized the findings in order to best answer the research questions. And while I did focus on individual methods at first, as stated by Braun and Clarke (2006), "the analysis is not a linear process where you simply move from one phase to the next. Instead it is more recursive in process, where you move back and forth as needed" (p. 16). The quantitative data was analyzed statistically, while the qualitative data was analyzed using thematic analysis (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006) and drawing on the constant comparative method (Bogdan & Biklen, 1998; Glaser & Strauss, 1967). Triangulation of the data also used thematic analysis in order to describe the case and the emerging themes related to the catalysts influencing students' metacognitive transformations in CHEM 200.

Quantitative data analysis.

The data from the SEMLI-S and the closed-ended questions from the midterm feedback survey were organized within Excel spreadsheets (Microsoft, 2011), and then analyzed using the statistical software SPSS (IBM, 2013).

For the SEMLI-S, the data for students who completed both the pre and post responses were entered into separate Excel spreadsheets (Microsoft, 2011). I then calculated the descriptive statistics (mean and standard deviation) for the five SEMLI-S dimensions for the pre- and the post-SEMLI-S by student. These statistics were calculated by averaging students' responses to the survey items addressing a particular dimension.

This pre and post data was then entered into SPSS (IBM, 2013) for analysis. Cronbach's alphas were computed for each SEMLI-S dimension to measure the internal consistency of the data set (Thomas et al., 2008). Cronbach's alpha is the lower bound of reliability and "is a group-level summary statistic or coefficient that describes the extent to which measurements from a specific sample of respondents are replicated or consistent across a set of items" (Helms, Henze, Sass, & Mifsud, 2006, p. 633). Typically, an alpha greater than 0.7 is desirable for instrument items (Field, 2009; Kline, 2000; Nunnally, 1978). Kline (2000) noted, however, that within social science research, where multiple factors can intervene, a lower alpha value might be due to factors such as a small number of items, multidimensionality of the instrument, and so forth. As such, Cronbach's alpha values not too distant from 0.7 are often acceptable. When an instrument is multidimensional, there is possibility of an over- or under-estimation of the Cronbach's alpha values (Cortina, 1993; Kline, 2000). As such, for this study, alpha values greater than or equal to 0.6 were acceptable

A paired-samples *t*-test (Gravetter & Wallnau, 2008) was used in order to determine if there was a statistically significant change in students' metacognitive dimensional scores. For this test, it was necessary to filter the data for pair-wise completion, i.e. for students who had completed both the pre- and post-administration of the SEMLI-S. A paired-samples *t*-test was run on the pre- and post-data for the five different SEMLI-S dimensions in order to compute a *p*-value. With a *p*-value greater than 0.05, the null hypothesis states that there is no difference between the two sets of scores. Thus, if the resultant *p*-value was less than 0.05, I would reject the null hypothesis and conclude that there was a statistically significant difference between students' pre- and post-SEMLI-S dimension scores.

The Wilcoxon matched-pairs signed-ranks test was performed to check the uniformity of the statistical effects of the paired-samples *t*-test. This test takes into account the size of the differences between two paired samples by ranking the mean scores of the pre- and post-tests (Bryman & Cramer, 1999). Examining the distribution of students allowed me to verify that the paired samples *t*-test results were representative and not skewed by a small group of students. I opted to run the Wilcoxon test in SPSS because the output included a table describing the number of students whose post-SEMLI-S scores were lower, higher, or the same as their pre-SEMLI-S scores (for each dimension).

Furthermore, I conducted an independent *t*-test and a paired-samples *t*-test for the 11 interview participants who completed both the pre- and post-SEMLI-S. These tests allowed me to gain a better idea of how this group of interview participants related to the 144 students who completed the SEMLI-S.

Descriptive frequencies were used to analyze the data from three closed-ended questions of the midterm feedback survey. The frequency of students' responses were summarized with either a bar or circle graph in order to gain a visual representation of the number of students who responded to a particular category. The organization and analysis of these three closed-ended questions in this way allowed for inferences to be made about which course resources students used, the usefulness of these course resources, and how students typically engaged in class.

Qualitative data analysis.

The analysis of qualitative data can be extremely tedious and time consuming, however effective transcription and coding techniques help to ease this process (Bogdan & Biklen, 1998; Creswell, 2009; Mertens, 1998). Thematic analysis was used to identify, analyze, and report patterns (or themes) within the data (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006; Patton, 1990). A theme was considered "something important about the data in relation to the research question, and represent[ed] some level of patterned response or meaning within the data set" (Braun & Clarke, 2006, p. 9). As suggested by Braun and Clarke (2006), the data analysis process included: familiarizing myself with the data by actively reading and re-reading; searching for meanings and patterns; organizing the data into meaningful groups; sorting codes into broader themes; identifying how each theme fits into the broader 'story" of the case; and choosing vivid examples that capture the essence of a particular theme. The constant comparative method by Glaser and Strauss (1967) also acted as a framework for discerning emergent themes within the data (as described in Bogdan and Biklen (1998, p. 67)):

1. Begin collecting data
2. Look for key issues, recurrent events, or activities in the data that become categories of focus.
3. Collect data that provide many incidents of the categories of focus, with an eye to seeing the diversity of the dimensions under categories.
4. Write about the categories you are exploring, attempting to describe and account for all the incidents you have in your data while continually searching for new incidents.
5. Work with the data and emerging model to discover basic social processes and relationships.

6. Engage in sampling, coding, and writing as the analysis focuses on the core categories.

Overall, the research questions acted as a framework for analyzing the data from the classroom observations, the open-ended midterm feedback survey questions, and the one-on-one interviews. More specifically, this framework guided me to discern:

1. Catalysts that students identified (explicitly and implicitly) as influencing their metacognitive transformations,
2. Aspects of the social environment influencing their metacognitive transformations and,
3. Signs of barriers and enhancers of metacognitive transformation among/between different groups of students.

The catalysts were identified within data analysis as particular resources, activities, interactions, or discussions that encouraged students to reflect upon their experience as learners. Aspects of the social environment included group activities and interactions (inside and outside the classroom) and students' accounts of how other people or resources influenced their metacognitive knowledge, experiences, and regulation. Finally, barriers and enhancers were identified based on students' accounts of the factors that could impede and/or enhance their metacognition and self-efficacy in CHEM 200.

While the qualitative analysis occurred within the framework of thematic analysis and the constant comparative method, there were slight variations in how the qualitative data was analyzed. For instance, the one-on-one interviews were transcribed verbatim and the experiences of each student were summarized and compared based on the research questions, emergent themes, and the SEMLI-S (Thomas et al., 2008) dimensions of metacognition (e.g. awareness, control, evaluation, planning, monitoring, and self-efficacy). The COPUS classroom observation forms were reviewed in order to pinpoint particular catalysts and to gain a more contextualized understanding of the social, learner-centered environment of the CHEM 200 classroom. Finally, the open-ended questions for the midterm feedback survey were read several times and then coded based on the frequency of students' responses and their relationship to the research questions. Chapter 4 provides a more contextualized description of how the various data collection methods were analyzed.

Triangulation.

The triangulation of the data required an intense process of reviewing, comparing, and contrasting the survey results and the written and verbal accounts of students' experiences throughout the semester (Boekaerts & Corno, 2005; Creswell, 2009; Nashon & Anderson, 2013; Patton, 1990). This process used multiple perceptions to clarify meaning and to "identify different ways the case [was] being seen" (Stake, 2005, p. 454). Similar to the analysis of the more qualitatively based items, I continued to follow thematic analysis and the constant comparative method to present a coherent, holistic projection of the critical catalysts (and their characteristics) influencing students' (social) metacognitive transformations throughout the CHEM 200 semester. The triangulation of this data also unveiled the supports and barriers influencing various students' metacognitive transformations.

While the SEMLI-S provided a quantitative perspective of metacognitive development over the course of the semester, the observations, written reflections, and interviews provided a more in-depth view of how and why students' metacognition had (or had not) developed over time and the influence of social aspects of learning. In this vein, the statistical analysis was complimentary to the qualitative analysis. Furthermore, after initial analysis, the preliminary findings were discussed with my supervisory committee, the instructor, the interview participants, and my colleagues to help with my critique and interpretation of the data.

Trustworthiness, ethics, & confidentiality.

The issue of trustworthiness is important within all research. A critic may question whether or not students' responses to the survey questions are authentic/genuine, and/or whether or not students' verbal and written accounts have been interpreted appropriately (Grove & Bretz, 2012). Lincoln and Guba (1985) argue that the validity and reliability of research should be gauged on its transferability, credibility, dependability, and confirmability. This trustworthiness issue was addressed through overlapping methodological approaches, member checks, and triangulation (Grove & Bretz, 2012). That is, the constant comparison and critique of the data from various data collection methods offered a robust representation of how and if students' metacognition was transformed. This comparison also "maximize[d] the probability that emerging assertions were consistent with a variety of data" (Thomas, 1999, p. 92).

When conducting this research, I considered the role that I played throughout the research process. Although the students provided a plethora of valuable information and insight, the collection and analysis of the data could contain biases through my interpretations (Mertens, 2010). Thus, I was aware of my own subjectivity and its influence throughout the research (Bogdan & Biklen, 1998; Thomas, 1999). To help alleviate these concerns, I met formally and informally with my committee members and colleagues to review my analysis and emergent results. I also contacted participants to ask them to review their transcripts and/or final narratives about their experiences. This engaged the participants within the research design and helped to ensure their experiences were reported to the best of my ability.

Furthermore, I was sensitive to the power I held as a researcher in deciding what quotes or themes to discuss and, more importantly, how I communicated and interacted with students throughout the data collection and analysis process. Merriam (1988) emphasizes that "empathy is the foundation of rapport" and throughout the research process, I strived to create a safe and collaborative space for discussion and honesty.

With respect to confidentiality, all hard copies of student work (surveys, workshops activity sheets, written reflections), consent forms, researcher observations, video/audio recordings, and interview data were kept in a locked filing cabinet. Any electronic data (survey responses, interview transcriptions) was stored on password-protected computers. To protect student personal identification, all identifying information (such as names) was removed from any transcripts and within the dissemination of the results. Pseudonyms were used in place of names, and physical descriptions of individuals were altered or removed.

Limitations.

All students in the two CHEM 200 sections were invited to participate in this study, but there was significant variation among the data collection methods as to who actually consented to or provided data for this work. While over 60% of students consented to have their data included in this study, not all of those students actually completed both the pre- and post-SEMLI-S or signed up for the one-on-one interviews. Similarly, a few students signed up for the interviews despite not having completed any of the previous surveys. Even though the data is composed of a variety of student experiences, it cannot be generalized statistically to the entire CHEM 200 population within these two sections. Furthermore, while the course was comprised of students from a variety of cultural and demographic backgrounds, this study focused specifically on students' metacognitive transformations and less on the influence of such backgrounds. As such, future research should consider more specifically how students' backgrounds and affective states could also influence their metacognition and self-efficacy.

One of the main criticisms of the descriptive case study is its lack of generalizability to other situations (Merriam, 1988); in the case of this research, other CHEM 200 sections and introductory organic chemistry course at large. This study focused specifically on the students within two sections of CHEM 200 taught by one instructor. Students' experiences in this course are unique, especially because they are the first iteration of students to be exposed to the new flipped classroom approach within CHEM 200. While this research offers many plausible implications for curricular and pedagogical movements within and outside of introductory organic chemistry, I caution educators and students to be wary of directly applying the results within their own context of teaching and learning.

Another limitation of this study is that it required me to be knowledgeable in both quantitative and qualitative methods (Teddlie & Tashakkori, 2009). While I have a background in both quantitative and qualitative methods and analysis, it was imperative that I check my work with experts in either field to validate my interpretations. The triangulation of the data allowed me to draw upon the strengths and mediate the weaknesses of methods reflected within a particular paradigm (Creswell, 2009; Teddlie & Tashakkori, 2009).

Furthermore, I negotiated and articulated how the (often competing) paradigms, methodologies, and methods associated with quantitative and qualitative work influenced my own epistemology and ontology. While my worldview lies more heavily in qualitatively-based constructivist-interpretivist frame (Anderson et al., 2009; Mertens, 1998), I also used and valued the objectivity and high response rate of quantitative methods of analysis. Despite these shortcomings, the combination of these paradigms/methods allowed for a more robust representation of the contextualization of the data (Treagust et al., 2014).

While scholars acknowledge the necessity of more longitudinally based studies to explore metacognition (Case & Gunstone, 2002; Zohar & Barzilai, 2013), this study was limited to taking place over four months. While there was ample opportunity to explore students' metacognitive transformations within this course, it would have been useful to investigate how students' metacognition continued to change (or not) in subsequent courses and years. Unfortunately, due to time and money constraints, and as this is the sole organic chemistry requirement for the population of interest, extending the study into another semester or year was not possible.

Finally, as mentioned previously, I acknowledge and am sensitive to how my own biases and interpretations came into play within this research (Merriam, 1988). Through communication with the instructor, students, and mentors, and by sharing my methodology in detail, I have attempted to provide transparency in the collection and interpretation of the findings.

Chapter 4: Findings

In this chapter I present my findings from the data collected for this study. First, I present the SEMLI-S data to reveal how the dimensions of students' metacognition and self-efficacy changed over the course of the semester. I then analyze the classroom observations to pinpoint various catalysts that the instructor implemented or suggested to enhance students' metacognition, self-efficacy, and learning. Next, the data collected via the student feedback/reflections and one-on-one interviews are presented to depict students' in-depth perceptions of and experiences with the various catalysts present both inside and outside of the classroom. The triangulation of data and how it addresses the research questions will be discussed in detail in Chapter 5.

4.1 SEMLI-S

While 222 and 243 students completed the pre- and post-SEMLI-S respectively, only 144 students completed both. Thus, the scores for these 144 students were used for the analysis of the SEMLI-S metacognitive dimensions. Abbreviations for the five dimensions are described in Table 6 and will be used throughout this analysis.

Table 6

Abbreviations for the SEMLI-S metacognitive dimensions

SEMLI-S Dimension	Overall	Pre-SEMLI-S	Post-SEMLI-S
Constructivist Connectivity	CC	CC1	CC2
Monitoring, Evaluation, and Planning	MEP	MEP1	MEP2
Self-Efficacy	SE	SE1	SE2
Learning Risks Awareness	AW	AW1	AW2
Control of Concentration	CO	CO1	CO2

The SEMLI-S required students to record how often they engaged with a particular metacognitive activity and was made up of a 5-point Likert scale. One represented "Never or Almost Never", 3 represented "Half of the time" and five represented "Always or Almost Always". The higher the score a student recorded the more likely they engaged with a given metacognitive dimension. For instance, a self-efficacy average above three meant that students were confident in their ability to succeed in this course more than 50% of the time.

Cronbach's alphas were computed for each dimension based on the raw data from the first and second administration of the SEMLI-S (Table 7).

Table 7

The number of items and the Cronbach's Alphas for the pre- and post-SEMLI-S scores by dimension

Dimension	Number of Items	Cronbach's Alpha		
		From Thomas et al. (2008)	Pre SEMLI-S (n=144)	Post SEMLI-S (n=144)
CC	7	0.84	0.901	0.915
MEP	9	0.84	0.809	0.851
SE	6	0.85	0.909	0.923
AW	5	0.77	0.650	0.735
CO	3	0.68	0.703	0.771

The Cronbach's alpha computed for this study were comparable to the alphas reported in the original SEMLI-S paper by Thomas et al., 2008. While there were slight discrepancies among the alphas within these contexts, the values for each dimension were above 0.60. Thus, the instrument's dimensions maintained high levels of internal consistency with the data, and therefore supported the use of the SEMLI-S within this context.

A paired-samples t-test was completed to compare the pre and post scores for each SEMLI-S dimension. Statistically significant differences existed if the computed *p*-value was less than a 0.05 level of significance. The means and standards deviations for each pre and post dimension are summarized in Table 8 and the results of the statistical significance tests are summarized in Table 9.

Table 8

Average SEMLI-S pre and post scores by dimension

Dimension	Mean (n=144)	Std. Deviation
CC1	3.15	0.761
CC2	2.85	0.854
MEP1	3.38	0.551
MEP2	3.23	0.612
SE1	3.34	0.826
SE2	3.22	0.931
AW1	3.89	0.525
AW2	3.88	0.612
CO1	3.67	0.772
CO2	3.66	0.819

Table 9

Results from the paired-samples t-test for each dimension in the SEMLI-S

Dimension	*t*-value	*p*-value
CC	4.60	<.001**
MEP	3.51	0.001**
SE	2.13	0.035*
AW	0.174	0.862
CO	0.141	0.888

***p*-value of less than .01
**p*-value of less than 0.05

This analysis reveals a statistically significant difference in students':

- Pre (M= 3.15, SD= 0.761) and post (M=2.85, SD=0.854) *Constructivist Connectivity* scores, t(143)=4.607, p<.001;
- Pre (M= 3.38, SD= 0.551) and post (M=3.23, SD=0.612) *Monitoring, Evaluation, and Planning* scores, t(143)=3.512, p=.001; and
- Pre (M= 3.34, SD= 0.826) and post (M=3.22, SD=0.931) *Self-Efficacy* scores, t(143)=2.131, p=.035.

Referring to the pre- and post-SEMLI-S means for these dimensions revealed a drop in the SEMLI-S scores from the beginning to the end of the semester. This indicated that over the course of the semester there was a decrease in students' perceptions of their ability: to connect with the material; to monitor, evaluate, and plan for their learning of organic chemistry; and to be confident in their learning of organic chemistry.

The paired-samples *t*-test revealed no significant difference in students':

- Pre (M= 3.89, SD= 0.525) and post (M=3.88, SD=0.612) *Learning Risks Awareness* scores t(143)=.174, p=.862; and
- Pre (M=3.67, SD=.772) and post (M=3.66, SD=.819) *Control of Concentration* scores, t(143)=.141, p=.888.

These results indicated that students' awareness of their learning difficulties and their awareness of their ability to control their concentration did not change significantly over the course of the semester.

I also performed a Wilcoxon matched-pairs signed-ranks test to check the uniformity of the statistical effects of the paired-samples *t*-test. The test takes into consideration the size of the differences between two paired samples by ranking the mean scores of the pre- and post-tests (Bryman & Cramer, 1999). The Wilcoxon test provided a breakdown of the number of students whose SEMLI-S scores for each dimension increased, decreased, or remained constant over the semester.

Table 10

The number of students whose mean SEMLI-S dimension scores increased, decreased, or remained constant over the course of the semester

Change in SEMLI-S	Number of Students				
Scores	CC	MEP	SE	AW	CO
Post < Pre	92	84	79	55	65
Post > Pre	42	43	52	66	54
Post = Pre	10	17	13	23	25

We can see that from Table 10 a small group of students did not skew the *t*-test results. The majority of students for the CC, MEP, and SE dimensions experienced a drop in their SEMLI-S scores over the course of the semester. Thus, I can accept that the statistically significant decrease in the CC, MEP, and SE dimensions over the course of the semester as indicative of the group and not an influence or effect of a small group of students with extreme scores.

As noted earlier, the results from the SEMLI-S were used to provide a window into how students' metacognition and self-efficacy changed over the course of the semester. These results were compared and contrasted with the findings from the classroom observations, student feedback/reflections, and the one-on-one interviews to gain a more grounded understanding of the catalysts (and their characteristics) that influenced students' metacognition and self-efficacy in CHEM 200.

4.2 Classroom Observations

Classroom observations were utilized for two main reasons: to pinpoint catalysts that the instructor or I distinguished as resources/moments/interactions/activities for enhancing students' metacognition and self-efficacy in the course; and to observe the dynamic and structure of the environment within the classroom boundaries.

Pinpointing potential catalysts for metacognitive transformation.

While using the COPUS (Classroom Observation Protocol for Undergraduate Science) (Smith et al., 2013) for conducting classroom observations of two sections of CHEM 200, I noted any significant points at which the instructor verbally offered advice to enhance student learning or provided students with resources to enhance their learning. Reviewing and coding the COPUS documents from each class resulted in the creation of a list of the resources the instructor provided throughout the term and the frequency at which these resources were presented (Table 11). The resources were categorized into the following groups: in-class CHEM 200 resources; CHEM assessment; out-of-class CHEM 200 resources; and external resources. Based on my experience and observation of the students' engagement with resources, I was able to deem these as *possible* catalysts for metacognitive transformation. Of course, there is a possibility that my observation and

Table 11

A summary of the possible catalysts for metacognitive transformation (drawn from the classroom observations)

Classification	Catalyst	Description	Frequency	Student Engagement
In-class CHEM 200 Resources	Learning Sequence	A diagram describing the structure of the course and how students can prepare for examinations	6 times throughout the first three weeks of class. Once again before the first and second midterm.	Students appear to be listening, but few were writing down the sequence.
	Deliberate Practice article	Instructor had students read an article about deliberate practice and discussed it in class.	Occurred once on the second day of class.	High engagement in both small group and in whole class discussion.
	Bjork Study Strategies Article	An article about the psychology behind how undergraduates should study.	Provided to students explicitly on the second week of class and referred to at least 6 other times throughout the semester.	Most kept a copy of it but difficult to know if students actually read it or used it.
	Suggestions for how to study for midterm and final examination.	During class instructor would ask students to take notice of suggestions for how to study for upcoming exams. Occasionally students would discuss the strategies in a small group.	Generally occurred throughout the semester. Explicit documents or suggestions given at least 2 weeks prior to an exam.	Students appeared to be listening, but few seemed to be writing suggestions down.
	Reaction/mechanism summary sheets	Instructor provided general summary template for students to use to distinguish characteristics of substitution and elimination reactions. The instructor also provided one to help students understand nucleophilic acyl substitution.	The summaries were provided prior to students learning the reactions/mechanisms and referred to on a weekly basis.	The summary table for nucleophilic acyl substitution was used in class and students engaged with it.
	Pre-midterm #2 material summary	Students were given a sheet and in groups listed what they already knew about the topic (without consulting their notes or Google).	This occurred just after midterm #1 and before the students started learning material for midterm #2.	Engagement was high but I noticed a few students going through their notes or searching for topics online.
	Learning Goals Document	A chart with the course learning goals matched to textbook readings and online problem sets.	Given to students in the first class and alluded to every class.	Difficult to observe whether students were using these.
	Group work in class	Students were encouraged to work on the worksheet problems in class with their peers.	Daily in class	About 80% of the students appeared engaged with their peers.

Classification	Catalyst	Description	Frequency	Student Engagement
CHEM 200 Assessment	In-class quizzes	Students would be given 10-13 minutes to complete the quiz. They took it up in class (they marked each others) or it was handed in and the Teaching Assistants marked it. For quiz #3 students answered multiple choice clicker questions to get immediate feedback prior to midterm.	Every 2 weeks.	The class was practically full every time there was a quiz and all students were writing.
	Clicker questions	Multiple-choice questions in which students would select an answer, then discuss their reasoning in a group, and then they would answer for a second time. The instructor created the questions in order to address common misconceptions.	At least 5/week.	Most students would have their clickers out and would be discussing the question.
	Carbonless copy paper activities	An activity where students would use three-piece carbonless copy paper to go through steps for writing and correcting a chemical mechanism. On the first page the students would attempt drawing the mechanism (and would hand this in). On the second page, students would correct their work (and hand this in). Students could then keep the third page with their work and corrections on it.	About once or twice a week within the last two months of the class.	The majority of students completed the mechanism as it contributed to part of their participation grade – but a lot of students forgot to bring their carbonless copy paper to class with them.
	Sapling Learning Homework	Optional online problem sets to test student understanding.	Assignments due roughly every two weeks	The majority of students signed up to complete these homework assignments.
	Midterm Examinations	Cumulative midterm examinations to test student understanding via multiple choice and written questions.	The first midterm was within the 5 week of class and the second midterm was within the 9th week of class.	These occurred outside of class in an evening timeslot (all sections completing the midterm at the same time).

Classification	Catalyst	Description	Frequency	Student Engagement
Out-of-class CHEM 200 Resources	Face to Face Office Hours	Face to face opportunity to gain feedback on learning and to help clarify the content. The instructor offered office hours at different times each week to accommodate student schedules. Students were also encouraged to book an appointment if the times did not fit their schedule.	Three hours a week for the entire semester.	The instructor informed students of the office hour dates/times in every class.
	Virtual Office Hours	These occurred in the evening and students could sign in from their computer and ask the instructor questions. The instructor could share her desktop so students could see how she works through and explains problems. The videos were archived so students could refer back to them.	Prior to and directly after the midterms to review the midterm content.	The instructor reminded students about the virtual office hours prior to and after the midterm examinations.
	Piazza Online Forum	Online forum in which students can ask one another questions about various homework problems and the course content. The course instructor monitors it.	Students can choose when to participate.	Activity increases prior to midterm and final examinations.
	Study strategy workshops	After the first midterm, students with a 55% average or lower were emailed by the instructor and asked to attend one of the three study strategy workshops (held outside of class). Within class, all students were invited to attend.	Three sessions were held about 1-2 weeks after the first midterm.	Roughly 50 students attended the workshops.
External Resources	SOS and Beat Your Course (BYC) Sessions	These sessions are external to the course but are review sessions run by senior undergraduate students.	Student representatives came into the class prior to the midterm and final examinations to encourage students to attend.	Unsure how many students from sections 103 and 108 utilize these resources.

interpretation of student engagement may not represent what the students perceived as influential to their learning (Anderson et al., 2009). Students' accounts about these and additional catalysts were explored more specifically via the midterm feedback survey and the one-on-one interviews.

In-class CHEM 200 resources.

Throughout the term, the instructor constantly encouraged students to reflect on their learning experiences and modeled how they might approach solving a particular problem or how they might study for assessments. Within the very first class, she presented a learning sequence (Figure 4) that described the general structure of the course to guide students in how they could prepare for examinations.

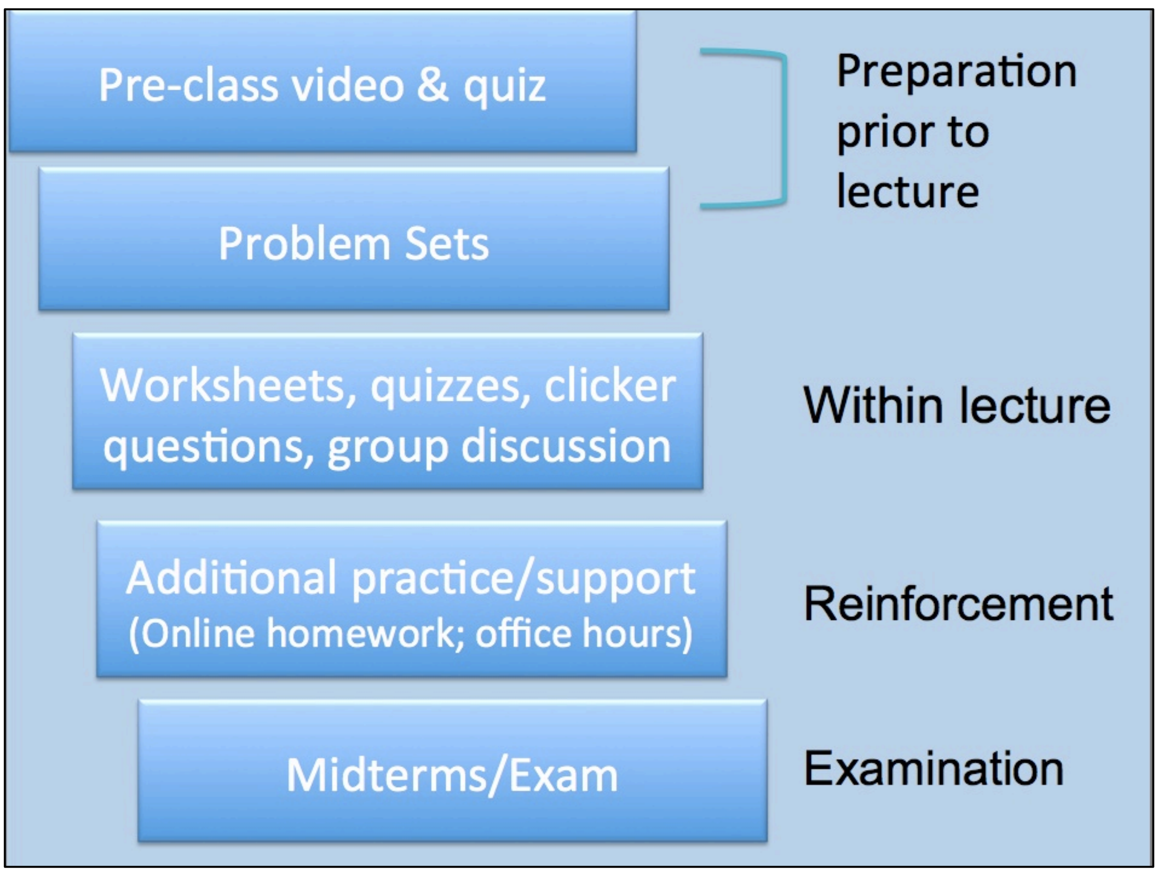

Figure 4 A learning sequence provided to CHEM 200 students on the first day of class.

This sequence was presented six times throughout the first three weeks of the course and once again after the first midterm. Along with this learning sequence was a document describing the learning goals of the course accompanied by select textbook readings and problem set questions. Ideally, this introduction would help students to plan how they were going to learn the course material.

In order to engage students more directly with their learning, the instructor assigned an article on deliberate practice (Colvin, 2006) and another on study habits (Carey, 2010) for homework on the first day of class. When the students arrived on the second day of the course they were asked to form groups and to discuss their perceptions of the article. Students animatedly discussed the articles (I could see many with it printed out on their desks or on their computer/phones) and together as a class they talked about deliberate practice as small steps towards learning, that feedback on your learning is essential, and that when studying you're not always trying to demonstrate your knowledge but working towards improvement. The instructor then noted, "It's about how you study. Studying should feel challenging and I understand that it might be difficult to motivate yourselves to do it".

In the class following the first midterm exam, the instructor provided groups of students with a sheet of paper with various topics they would be learning for their next midterm. The students had learned these topics briefly in their first-year chemistry course, and the instructor was curious as to what information the students remembered. While she asked students not to use any resources (Google, textbook, their notes) to fill out the sheet, I noticed many students using their phones, laptops, and textbooks during this activity. She told them it was important to know where they have gaps in the knowledge and that "what's interesting about learning is how easy it is to forget things".

Throughout the term the instructor also gave students explicit advice about, or resources for, how they could study for the course. The suggestions and summary templates were posted on a PowerPoint slide at the beginning and/or end of the class and included within a resource folder on the online course management system. The majority of suggestions were based on literature in studying/learning/psychology or from her experience from teaching the course for nine years. In the last month of the course, the instructor used one of the summary templates within class to model how students could use a table to summarize and categorize various reactions and their properties.

CHEM 200 assessment.

Various methods were used for assessing students' learning throughout the course, with most assessments occurring within the classroom. Student participation made up 10% of students' grades and included their performance on in-class quizzes and their participation in carbonless copy paper activities and clicker questions. Each of these assessments or activities was used to encourage students to reflect on their learning and to adjust their studying or learning strategies accordingly. Upon the return of their first in-class quiz, the instructor emphasized the importance of receiving feedback and how students could use this feedback. She encouraged students to "reflect on what [they] know in order to help [them] fine tune what [they] don't know". Every time an in-class quiz was returned to the students, she emphasized the need for students to use the quiz as information; as feedback on how they are studying and which topics they need to review in more detail.

When introducing the carbonless copy paper activities that allowed students to write a mechanism and then correct their own work (on the next carbonless page), the instructor stated that "It's not about getting the question right but getting similar questions right in the future…Don't worry about getting it right, it's about the process". This suggestion was echoed when she introduced the Sapling learning homework that offered bi-weekly problem assignments that had students practice what they know and don't know.

Out-of-class CHEM 200 resources & external resources.

External to the classroom, the instructor provided more targeted opportunities for students to improve their learning. After the first midterm, students who failed or performed poorly on the first midterm received an e-mail from the course instructor encouraging them to sign-up for a study strategy workshop. The rest of the students in the class were informed of the workshop in class. Three workshops were run by the course instructor and engaged students in activities that were designed to help students: assess their current approaches to studying/learning organic chemistry; match the course learning goals to midterm #1 problems; brainstorm the properties of the learning goals and how students could use the goals to test their understanding; and to set goals for how they will improve their studying/learning for the second midterm. During the workshops students worked individually and with their peers to complete the activities and accompanying worksheets.

Overall, 74 students attended one of three workshops and all of them consented to having their written feedback included in this study. Over 85% of the students perceived the workshop and accompanying activities as very or somewhat useful. Interestingly, 96% of students perceived setting personal goals to prepare for the next midterm as useful for their learning. Students expressed that they rarely engaged in this type of goal setting when studying and rarely took the opportunity to discuss their strategies with others or to acknowledge their strengths and weaknesses as learners. Some students commented that studying for them was a “passive” exercise where they tried studying the way they always had. About 80% of the students enjoyed hearing about the strategies that their peers used to study with 10 students commenting that they were happy to see they weren’t the only ones having difficulty with the course. One student appreciated, "learning to '"actively'" study and know that others are in the same situation as me. Good to hear it from my own prof".

And in particular, students also mentioned the usefulness of using the learning objectives as guides for studying. Trying to categorize the question with respect to an objective gave them a grounding of what was being tested and where it was present in the course content: "I think matching the learning objectives is really useful because I usually look at one question and just have no idea where to start".

In addition to this workshop targeted towards low performing students, the instructor also made herself available through both face-to-face and virtual office hours. While the face-to-face office hours occurred three times a week throughout the semester, the virtual office hours acted as a review session prior to and after both midterms. The virtual office hours occurred in the evenings and the students could sign in online to listen to and ask questions of the instructor. Furthermore, students could join an online discussion forum called Piazza that the instructor monitored. This acted as an environment for students to discuss questions with their peers and to answer each other's questions.

Finally, the instructor advocated for external resources including Beat Your Course (http://www.beatyourcourse.com/) and Students Offering Support (SOS) CHEM 200 (http://ubc.soscampus.com/). These programs were facilitated by senior undergraduate students and acted as review sessions prior to exams to help students learn and study the material. While this was discussed and introduced in class by the instructor, I had no direct observation or contact with the individuals running these review sessions as they were external to the course offerings.

Dynamic and structure of CHEM 200 in this study.

Conducting classroom observations allowed me to witness a dynamic, engaging classroom. Within the very first class and throughout the semester the instructor encouraged students to work with one another both inside and outside of the classroom. She stated that “I want you to be successful. I want you to work together, to learn together”. She further emphasized the need for students to explain their reasoning to one another in order to understand the underlying concepts of the question for “the answer is just part of the story”. There was a desire that this process would help students to see the various approaches their peers were taking to solve problems and to study for the course.

As a caveat of group work, the instructor advised students to try the problems and to not just wait for when the class took up the answer. For in organic chemistry, “once you know the answer, everything seems obvious or makes total sense”. After noticing several students who did not write down the suggestions provided by the instructor, she commented that, “what I want you to do it take a lot of notes. If you just write the answer and not the steps or my explanations, later you might not know how you got there”.

The observations also allowed me to see how students interacted with one another in class. Throughout the semester students appeared extremely engaged with one another and worked diligently on the worksheets. Within the second week of the class I even overhead two students, who had never met before, introduce themselves and start working on a problem together. While the first student mentioned they did not understand how to start the problem, the other student commented on what steps they found useful to get started.

As an observer I often shifted where I sat in order to gain a better sense of how students were engaging. In general, students who were seated in the back three rows of the lecture hall (designed for 300 students) rarely interacted with one another. The most engaged, inquisitive students sat either in the middle of the class or right in the first three rows. And while this structure of student engagement in the classroom held through the remainder of the semester, the attendance shifted as the term progressed. And as we moved into the third month of class, attendance dropped from about 220 students to 170. These values are an estimate based on the number of students who responded to clicker questions. While this number might be slightly higher, it was evident by the increasing number of empty seats that students were choosing not to come to class or had perhaps withdrawn from the course. Despite the waning student attendance throughout the term, the class remained upbeat. The instructor exerted a lot of effort to keep both the classroom environment and their attitude positive. Interactions remained high in the classroom despite the decreasing number of students in class.

Summary.

These observations provided a rich description of the classroom environment and the possible catalysts influencing students' metacognitive transformations. It also presented some questions around students' perceptions of the curriculum and pedagogy and why fewer students were attending class or engaging only with particular resources. These concerns were explored in more detail via information collected from the midterm feedback survey and the one-on-one interviews.

4.3 Midterm Feedback Survey

Midway through the semester, students were asked to complete a survey to provide feedback on their experience in the course so far. The survey asked students about particular assessment methods or teaching techniques and to elaborate on their strengths and weaknesses as learners. The results of 255 students who consented for their data to be used for this study were analyzed.

Use and usefulness of CHEM 200 resources.

Figure 5 is a summary of students' accounts about whether or not they used particular in-class and out-of-class resources provided within CHEM 200. The in-class resources included: quizzes; group work (In-class GW); and the carbonless copy paper activities (CCP). The out-of-class resources included the: face-to-face (F2F) office hours, virtual office hours, study strategy workshops (SSW); Sapling homework assignments; and chemistry resource centre (Chem RC).

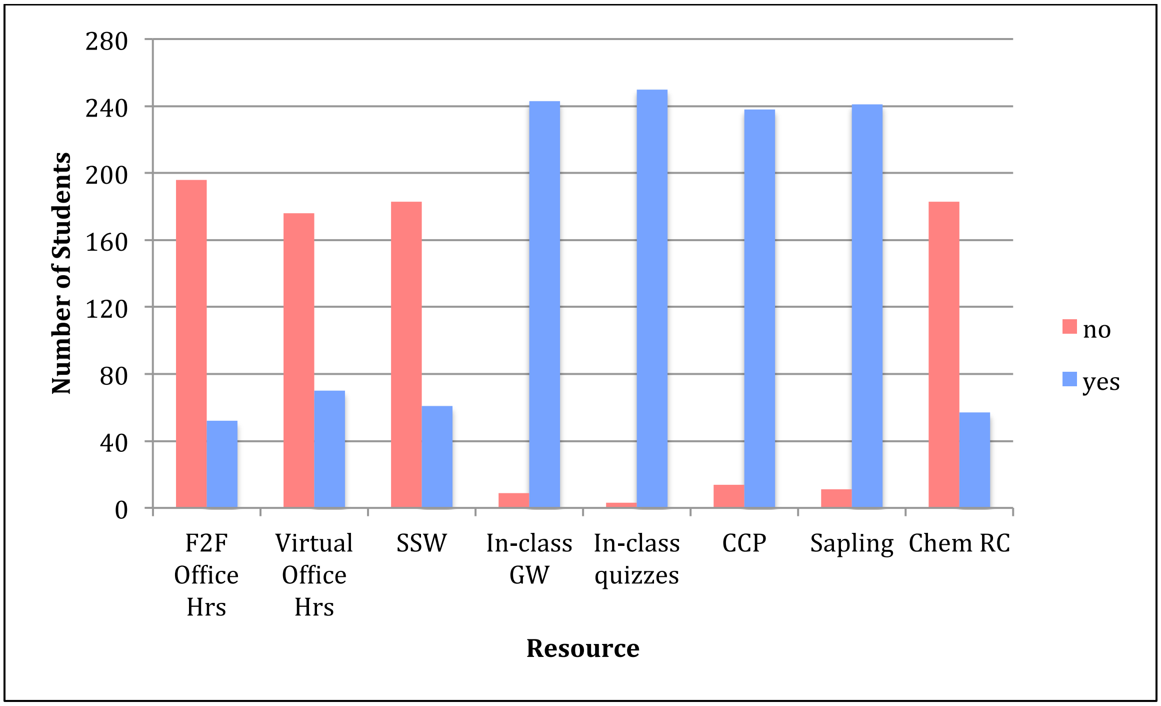

Figure 5 A summary of the resources students did or did not use within the first 6 weeks of the course (n=255).

From Figure 5 it is apparent that the in-class activities were used most frequently along with the Sapling homework assignments. It's likely that students engaged more directly with the Sapling because their engagement with this assignment provided practice and lowered the weight of their midterm exam scores on their final grade. Other than the Sapling homework assignments, only about 25% of students engaged with the office hours, study strategy workshops or the chemistry resource centre.

Students were also asked to indicate how useful they found each resource. To reflect similar response rates and to more easily distinguish students' responses, I have split the data into two separate figures. Figure 6 summarizes students' perceptions of the usefulness of the in-class quizzes, group work, carbonless copy paper, and Sapling learning homework. Figure 7 on the other hand, summarizes students' responses towards the office hours, study strategy workshops, and chemistry resource centre.

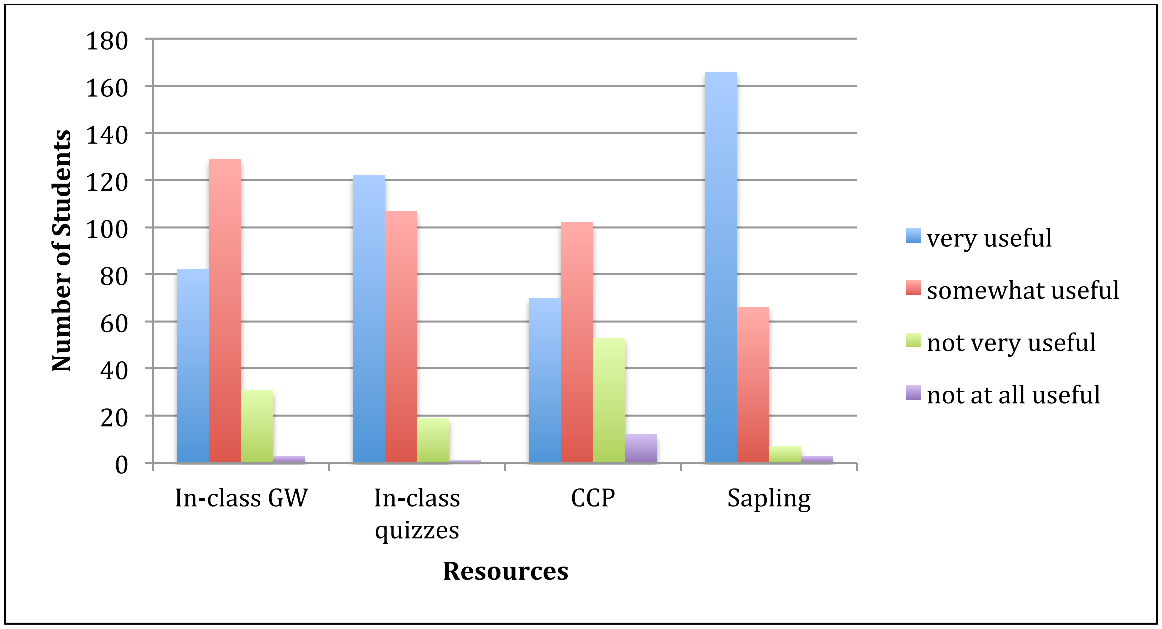

Figure 6 The perceived usefulness of the CHEM 200 resources with the highest participation.

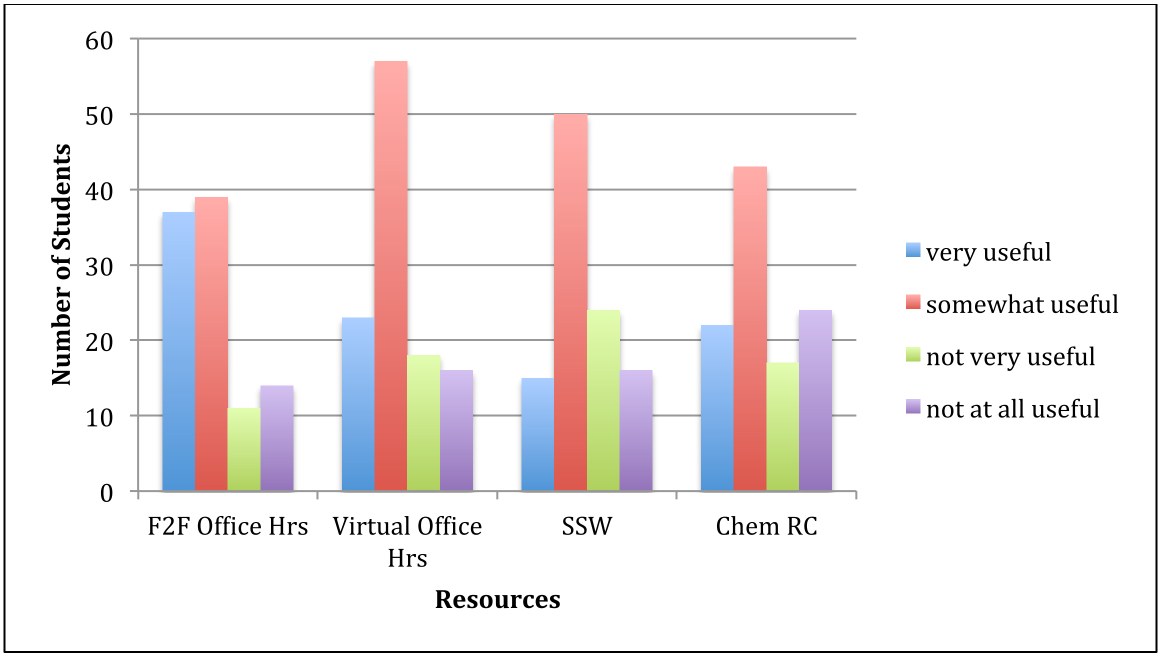

Figure 7 The perceived usefulness of CHEM 200 resources that are used by a smaller fraction of students.

Overall it seems that the majority of the students found the above resources as useful or somewhat useful. The usefulness of the Sapling learning homework, however, appears to stand out as the most useful with 69% of respondents (n=242) perceiving this resource as very useful and 27% perceiving it as somewhat useful. The in-class quizzes (n=249) and group work (n=245) were the next highest with 92% and 86% of students perceiving these resources as very or somewhat useful, respectively. The remainder of the items had at least 60% of the students considering the resource as very or somewhat useful.

In-class student engagement with worksheets/peers.

In addition to sharing their use of and the perceived usefulness of various resources, students were asked to more specifically indicate whether they worked with others or alone within lecture, and the effort they would put into solving a given problem (Figure 8).

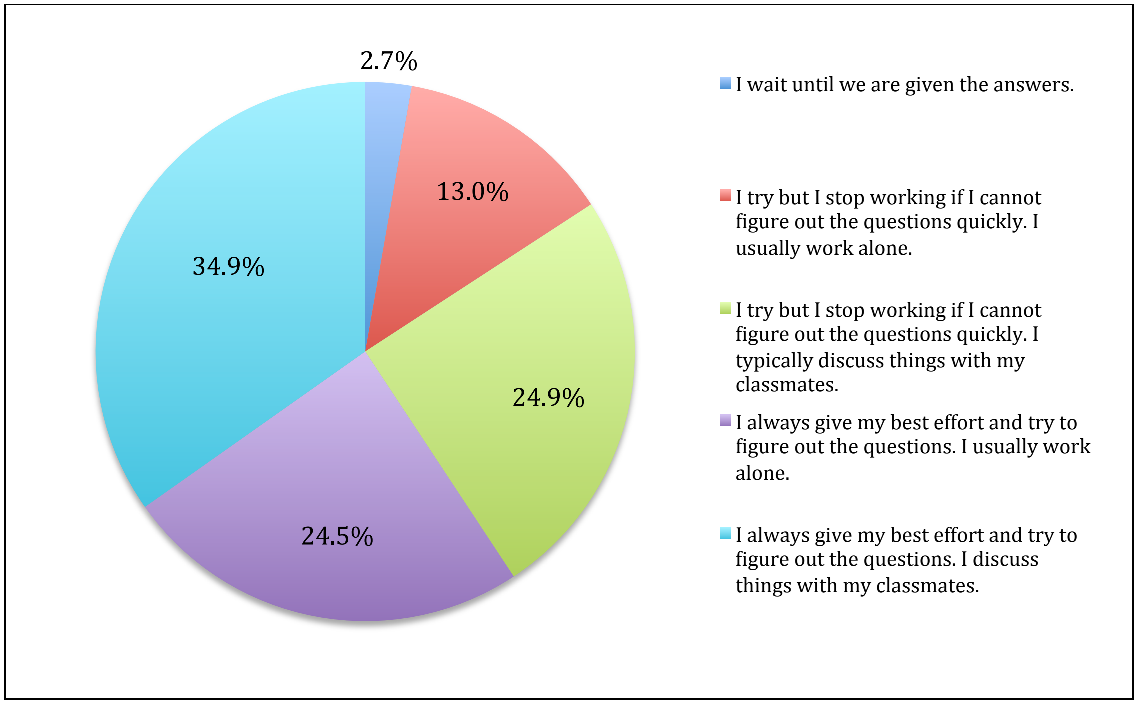

Figure 8 Students' accounts of how they usually approach the in-class worksheets (n=253).

This figure bears witness to the diverse ways in which students engaged with the worksheets in class. While 2.7% of students sat and waited until the answers were given, 37.9% of students stopped working if they couldn't find solutions quickly and almost 60% of students gave it their best effort. This data also provided insight to whether or not students tended to work with their peers in class. While 37.5% often worked on their own in class, almost 60% engaged with their classmates when working on the in-class problems.

Open-ended responses to learning challenges and improvements.

At the end of the survey, students were asked to answer open-ended questions about their learning in the course. The first open-ended question asked students to describe "your biggest challenge in learning the material in CHEM 200". The responses of 246 students were coded with the main themes presented in Table 12.

Table 12

Major themes emerging from students' responses to the question: "What has been your biggest challenge in learning the material for CHEM 200?" (n=246)

Theme	Number of students who commented
The vast amount of content to learn	56
Recognizing, understanding, differentiating the similarities and differences among various types of reactions and mechanisms	53
Time management (personal time management and difficulty finding time to learn all of the required material)	33
Keeping up with the fast pace of the course	22
Memorizing rules, reactions, and mechanisms	18
Being able to apply what I have learned to new problems	14
Having to teach myself everything (because there is no lecture in class)	14
Not having a strong enough grounding coming into the course	7
New teaching method (flipped classroom) is new and difficult to manage	6
Lack of motivation	3
Adhering to a consistent study schedule	3
Effective problem solving	3
Learning along outside of class or not knowing anyone in the class	3
Being able to organize large amounts of information	2

Students' main challenges centered on the course content and time management. Students felt there was too much information and that the demands of the course exceeded that of their other science courses. While some students discussed their lack of time management skills as a challenge, others commented that the vast amount of course content, and the fast pace at which it was to be learned, was too overwhelming. For instance, one student commented that "the amount of information!!! Its [*sic]* so much to do before every class when you have class 3 times a week. And I'm actually an organized person."

More specific to learning content, 53 students mentioned their struggle with recognizing, understanding, and classifying the various reactions and mechanism they were expected to know for the course. Students expressed that having to learn all of the properties of the reagents, reactants, and products for a variety of reactions was difficult to manage. One student noted difficulty with:

> Being able to look at the products of a reaction (or vice versa) and figure out which reaction mechanism it proceeds through. Since we have learned so many different reactions, I find it hard to choose the right one and understand why it proceeds through that specific mechanism.

Fourteen students also alluded to the fact that the course structure of watching videos outside of class and working on problems in class was difficult to adjust to and made them feel as though they had to learn everything on their own. For them, it was as though the instructor was absent and not teaching: “Not having someone to help me understand the concept well. A lot of things I feel that I’m required to know or find out on my own and that doesn’t feel good and makes me feel lost.”

While most students commented about course content, the course structure, and the difficulty with learning all the material in a given time, there were a few students who spoke specifically to their difficulty of knowing how to study effectively and how to understand the material and not just memorize it. Problems included:

> Organizing and summarizing large amounts of information by myself. I think I receive a lot of information from different sources. I feel like the knowledge I get from them are like pieces of loose papers hanging around and waiting to be organized into a binder of notes.

Within the midterm survey, students were also asked to describe how they might improve their learning and study strategies for the remainder of the course. The major categories from this open-ended question are summarized in Table 13.

Table 13

A summary of students' responses to the open-ended question: "How might you improve your learning/study strategies for the remainder of the course?" (n=244)

Theme	Number of students who commented
Do more practice problems or questions	98
Carve out more time or exercise better time management	34
Better prepare for class	29
Ask more questions or go to office hours/resource centre	25
Do more reading from the textbook	24
Pay better attention to the videos	18
Make better notes when watching the video and in class	17
Keep up with the material	10
Study more efficiently	9
Use and make summary sheets of the various reactions and mechanism	9
Study in smaller amounts more frequently	9
Use a study group	9
Refer to and use the course learning objectives	6
Hire a tutor	6
Keep notes about things I don't understand and reason/explain them	3
I don't know	3

The most common response from students with regards to how they could improve was "to do more problems", with one student commenting "Three words: practice, practice, practice." While practicing was an extremely important aspect of learning organic chemistry, and one they should have utilized, students did not engage meaningfully with the material when practicing problems. Some students commented that they needed not only to go through the motions of problem-solving but to actively engage with the questions and what they know and do not know: “Understanding the answers to problems fully, not just looking over it and falsely thinking - Cool. I get it.”

About 30 students mentioned the necessity of actively engaging with the course videos and quizzes before class in order to take advantage of the problem-solving that happened in class. One student mentioned the need to “get my head out of my ass and stop watching videos an hour before class and take some notes on it.”

Some students commented that learning chemistry was out of their comfort zone as they are use to biology and psychology courses that rely on reading and making larger generalizations: “I feel like chemistry is one of those courses where practice is what counts (unlike biology, where memorization and understanding processes seem to matter more).” And while the majority of the students were able to articulate some way to improve their learning, three students honestly responded that they didn’t know what to do and that perhaps they should just “study harder and harder?”

While many of the students provided generalized comments about doing problems more often, a few students were more specific about what type of problems they would do and how often they would do them. One student even mentioned that they would engage in deliberate practice. These students, although few, expressed a more specific plan for their learning. Furthermore, these students also mentioned checking their understanding with the instructor, their peers, or a tutor:

> Doing the problems a bit more ahead of time and discuss the knowledge basis for them with an equally or more highly educated group on these topics instead of trying to memorize aspects of mechanisms. I want to understand the why, and in this way I think I may be able to.

Keep at it. Keep practicing a little bit every day. I am considering a tutor just to help me straighten out my reactions. I thought I understood them but my quiz scores would say differently and with the upcoming midterm I am going to see the prof on Monday.

Summary.

This information revealed the complexity of student learning and engagement within a given course. While students found the in class resources as useful to their learning, there was apprehension towards the use of these resources. While the students who engaged with the office hours, study strategy workshops, content summaries, and study advice perceived them as very or somewhat useful, the majority of students were concerned with how to learn the material within the time given. And furthermore, students struggled with how to implement the strategies required to make them successful in the course. These findings and concerns are elaborated upon within the one-on-one interview analysis and in the remaining chapters.

4.4 One-on-One Interviews

To provide a more in-depth, personalized look into the catalysts influencing students' metacognitive transformations in CHEM 200, I conducted one-on-one interviews with 26 students. The demographics of the students who were interviewed and the results of the interviews are discussed in the following sections.

Demographics of the students involved.

While 30 students were registered for one-on-one interviews, four students did not complete the interviews due to other commitments during the exam period. Overall, 26 students completed the one-on-one interviews during the exam period in December of 2013. Table 14 is a summary of the students' demographics, the data collection methods they participated in, their examination and final grades, and if this was the first time they

Table 14

A summary of the demographics of the students who took part in the one-on-one interviews

Student Code	Gender	Year of study	Retaking course	SEMLI-S Completed	Midterm Survey completed	Midterm 1 Grade	Midterm 2 Grade	Final Exam	Final Grade
1	Female	2	-	Pre & Post	Yes	A-	A+	A	A+
2	Male	2	-	Pre & Post	Yes	C+	B+	C	B
3	Male	2	-	Post	Yes	F	D	C+	C+
4	Female	2	-	Pre & Post	Yes	B-	D	D	C
5	Male	2	-	-	Yes	C+	A+	A+	A+
6	Male	3	-	-	Yes	B-	A-	A	A
7	Male	2	-	Post	Yes	C+	C	C	B-
8	Female	2	-	Pre & Post	Yes	A+	B	B+	A-
9	Male	2	-	-	Yes	C+	F	B	B-
10	Female	2	-	-	-	D	C-	C-	C
11	Female	2	-	-	Yes	F	F	C	C-
12	Male	5	Yes	Pre & Post	Yes	C-	C+	C	C+
13	Female	2	-	Pre	Yes	C	C-	C	C+
14	Female	2	Yes	Pre	Yes	B+	C+	C-	C+
15	Male	3	-	-	-	B-	B+	A-	B+
16	Female	2	-	-	Yes	F	D	C	C-
17	Male	2	-	Post	Yes	B-	B+	D	C-
18	Female	2	-	Pre & Post	Yes	C	F	C	C+
19	Female	4	Yes	Pre & Post	Yes	A-	A+	A+	A+
20	Male	3	-	Post	Yes	B+	A+	A-	A
21	Female	2	-	Pre & Post	Yes	F	D	C	C-
22	Female	1	-	-	Yes	C+	F	B-	B-
23	Female	2	-	Pre & Post	Yes	B-	A-	A	A
24	Female	3	Yes	Pre & Post	Yes	A-	B+	B	A-
25	Female	2	-	-	Yes	C-	C-	B	B-
26	Female	3	Yes	Pre & Post	Yes	B	C+	A-	A-

had taken the course. Students' numerical grades were categorized based on the UBC grading scheme (see Appendix C) in order to increase student confidentiality.

Overall, the majority of students were in their second year, taking the course for the first time, and had completed the midterm survey. Students' completion of the SEMLI-S varied however. Eleven students completed both the pre- and post-SEMLI-S, whereas two and four students completed only the pre- or post-SEMLI-S respectively. Despite nine students not completing either administration of the SEMLI-S, these students were still asked to comment on aspects surrounding the five SEMLI-S dimensions.

I conducted an independent *t*-test and a paired-samples *t*-test to detect for statistically significant differences between the interview participants pre- and post SEMLI-S scores. While 26 students participated in the interviews, only 11 of these students had completed the pre- and post-SEMLI-S. It is these 11 students' data that were used for this statistical analysis.

The independent *t*-test was used to draw a comparison between the pre-SEMLI-S scores of the 11 interviews participants and those of the 144 students who completed the pre-SEMLI-S overall. This test helped me to better understand if and how these 11 students were representative of the overall group of survey respondents. Tables 15 and 16 summarize the pre-SEMLI-S means and standard deviations, and the results of the independent *t*-test, respectively.

Table 15

Means and standard deviations for the 11 interviews participants and the 144 students who completed the pre-SEMLI-S

Dimension	Interview Participants (n=11)		Entire Group (n=144)	
	Mean	Std. Deviation	Mean	Std. Deviation
CC	3.10	0.932	3.15	0.761
MEP1	3.55	0.526	3.38	0.551
SE1	3.20	0.827	3.34	0.826
AW1	3.82	0.397	3.89	0.525
CO1	3.67	0.737	3.67	0.772

Table 16

Results from the independent t-test comparing the 11 interview participants and 144 students who completed the pre-SEMLI-S

Dimension	*t*-value	*p*-value
CC	.187	0.852
MEP	-1.04	.301
SE	.524	.601
AW	.424	.672
CO	-.690	.945

The independent *t*-test revealed no significant differences between the 11 interview participants' pre-SEMLI-S scores and that of the 144 students. This result indicates that the 11 participants who were interviewed constitute a representative sample of the larger group.

Tables 17 and 18 summarize the pre- and post-SEMLI-S means and standard deviations of the 11 interview participants and the results of the paired-samples *t*-test, respectively. As stated previously, this information helped me to determine the relationship between the 11 interview participants and the 144 students who completed both the pre- and post-SEMLI-S.

Table 17

Average SEMLI-S pre and post scores for the interview participants (n=11)

Dimension	Mean (n=11)	Std. Deviation
CC1	3.10	0.932
CC2	3.36	0.973
MEP1	3.55	0.526
MEP2	3.13	0.755
SE1	3.20	0.827
SE2	3.21	0.791
AW1	3.82	0.397
AW2	3.96	0.497
CO1	3.67	0.737
CO2	3.39	0.807

Table 18

Results from the paired-samples t-test for each dimension in the SEMLI-S (n=11)

Dimension	*t*-value	*p*-value
CC	-0.874	0.403
MEP	3.33	0.008**
SE	-0.490	0.962
AW	-1.05	0.318
CO	1.41	0.190

***p*-value of less than .01

Similarly to the SEMLI-S population (n=144), the 11 interview participants had a statistically significant drop in their pre (M=3.55, SD=.562) and post (M=3.13, SD=.755) MEP scores (t(10)=3.33, p=.008). The paired-samples *t*-test also revealed no significant differences in students':

- Pre (M= 3.82, SD= .397) and post (M=3.96, SD=.497) *Learning Risks Awareness* scores t(10)=-1.051, p=.318;
- Pre (M=3.67, SD=.737) and post (M=3.39, SD=.807) *Control of Concentration* scores, t(10)=.1.406, p=.190

Unlike the group of 144 students, the analysis of these interview participants' responses did not reveal a statistically significant drop or difference in their CC and SE scores. While there was no significant drop in the interview participants' pre (M= 3.20, SD= .827) and post (M=3.21, SD= .791) SE scores, their scores were very close to the post SE score of the 144 students (M=3.22, SD=.931). Thus, while the large group (n=144) experienced a drop in their SE, the mean post-SEMLI-S scores for both groups were 3.21 and 3.22. In addition, the large group had a statistically significant drop in their CC scores, but the smaller group of 11 students actually had a significant increase between their pre (M=3.10, SD=.932) and post (M=3.36, SD=.973) CC scores.

This statistical comparison revealed that this group of 11 interview participants was partly representative of the overall population of 144 students. Both groups experienced a statistically significant drop in their MEP scores and no significant difference in their AW or CO scores. There were no similarities however, in the pre and post patterns for the SE and CC dimensions among the 11 interview participants and the SEMLI-S population. The qualitative methods and analysis helped to provide a more contextual perspective of how and why the students' metacognitive dimensional scores increased or decreased significantly, or remained the same over the course of the semester.

When looking at students' examination grades, there was little consistency within scores for each exam or between scores across the two exams. From the first midterm, students' marks either increased or decreased by one or two letter grades and rarely remained constant. Another point of discussion concerns the five students who were taking the course for the second time. These students had failed or withdrawn from the course previously and their interviews offered an interesting comparison about the teaching and their learning from one iteration of the course to the next.

During my analysis and interpretation, I was cautious of regarding these 26 students' experiences as entirely representative of all students in CHEM 200. Students' participation in the interviews was voluntary, and as such limited the generalizability of the results. Despite this concern, the interviews provided contextual, personalized insight into the catalysts for metacognition transformation in CHEM 200.

Initial impressions of CHEM 200.

I began each interview by asking the students the following question: If someone were to ask you what your experience in CHEM 200 has been like, what would you tell them? This question resulted in rather candid and lengthy responses. Most of the students discussed their apprehension with the course while a few students discussed their appreciation and/or excitement for the course. To gain a sense of students' initial impression of CHEM 200, I inputted students' responses to this question into a Wordle (Feinberg, 2013) (Figure 9) to analyze the frequency of use of particular words.[2]

Figure 9 A word cloud of the interview participants' initial sentiments towards CHEM 200.

[2] In a word cloud, the frequency of word use is represented by the size of the text. For example, hard and tough are two of the largest words in Figure 8 because when describing their experience in the course, students used these terms most frequently.

While these sentiments were expressed at the beginning of the interview and encompassed students' overall impressions of the course, as the interviews developed students were more specific as to what elements of the course they feared/appreciated most, how their experience as learners and their confidence had shifted (or not) over the term, possible changes they would make to their learning approaches, and advice they would provide for incoming students about how to be successful in the course. The interviews revealed students' perceptions of catalysts influencing their learning in the course and provided further context for the SEMLI-S dimensions.

Catalysts (and their characteristics) for metacognitive transformation.

The following section will review some of the main catalysts that students perceived as influential to their learning strategies and confidence throughout the semester.

Performance-based assessments.

For almost all of the students, the first midterm was the first event that triggered students to study and, afterwards, to reflect upon their learning. All students mentioned that the midterm was a reason for them to "actually start studying" [Student 12, Interview Transcript] the course material. Three students began their studying about 1.5-2 weeks ahead of the first midterm, whereas most other students began the weekend before (five days in advance). And while all students mentioned that immediately following the midterm they had every intention to improve their study strategies, only about half of them felt they had made positive changes to their learning.

Almost all of the students commented that the in-class quizzes were useful feedback on their progress, and that they enjoyed having them, but that the high stakes assessment was students' first, major "realization that maybe you don't know things" [Student 2, Interview transcript].

> I really like the in-class quizzes…You get feedback on it and you would get to see what you're doing right and what you're doing wrong and what you need to work on. So… I thought that was really good feedback. [Student 16, Interview Transcript]

While the in-class quizzes provided feedback on students' learning, many commented that, as the quizzes did not hold the same weight as a midterm, they did not approach them with the same gravitas. Few students studied for the in-class quizzes explicitly, and as they were worth significantly less to their final grade, instead prioritized other responsibilities: "I tried practice problems and just went over my notes but yeah. I didn't do too much for them and that showed. But when you have other classes it wasn't really a top priority" [Student 10, Interview Transcript].

All but one student, however, held extremely positive perceptions of the Sapling learning homework. It was worth 10% of their grade and they felt it provided a good grounding in the main topics of the course. They were inclined to complete the homework assignments for, if they did, their midterms would be worth less of their overall grade. Students liked that "it was a place where you could test yourself" [Student 6, Interview Transcript] and that it was a safe place for making mistakes.

> Well, I like that it gave me a broad range of questions and it gave you hints but didn't tell you exactly what to do, so, that was kind of like my practice before I had a greater understanding. Like it wasn't my final practice, it was more my mid-practice questions. And if you got stuck there were hints and it was pretty easy to

get stuff right…And it wasn't so much about the grade I would get, it was more about not getting it right/wrong, but leading you towards the right answer which I thought was pretty helpful with regards to my learning. [Student 4, Interview Transcript]

In-class learning resources.

Throughout the term the instructor presented and discussed a variety of resources to help students with their learning in CHEM 200. The interviews offered the opportunity to examine students' perceptions of these resources in more detail and to explore how students monitored, evaluated, and planned their learning of organic chemistry.

As mentioned earlier in this chapter, at the beginning of the term the instructor repeatedly presented a suggested learning sequence and targeted readings for students to engage with in order to practice and prepare for examinations (Figure 4). Despite the suggestions of the instructor, few students actually remembered the learning sequence or what they had read in the articles, a typical response being, "Oh yeah. We did that at the beginning of the semester right?" [Student 17, Interview Transcript]. A couple of students did recall the learning sequence, but felt the suggestions were obvious. Despite seeing it as obvious, few actually engaged with it.

Although most students did not use the learning sequence, a select group of five students remembered the sequence in its entirety and were surprised others did not engage with it or recall it.

> Yeah definitely, I remember that. It was steps that would help you to be prepared throughout. A lot of people don't remember?...She went through like a learning map a few times and how you would approach the course and like – start now…but

even my parents will tell me to start something now but I won't listen to them until the day before. [Student 15, Interview Transcript]

At the beginning of the semester the instructor also provided students with a learning objectives document that paired each objective with textbook readings and problem set questions. Six out of the 26 students commented that "learning goals help to center my studying' [Student 1, Interview Transcript]; these students would use the learning goals and accompanying practice problems to check what they "know and don't know". Three students that attended the study strategy workshops mentioned that once they saw value in the learning objectives they used them to test their knowledge for future study. Another five students mentioned glancing at them, but expressed that they did not use them in depth.

One student in particular provided a very clear strategy for using the learning objectives to guide her study and understanding of the material. To prepare for the final exam, she wrote out general reactions and mechanisms for all of the learning goals on a large piece of poster paper. She then used this document as a means to classify various problems and to solidify her understanding of their distinct properties. Images of the students' work can be found in Appendix C.

Consistently throughout the term students were encouraged to create summary charts in order to help them differentiate and recognize the various types of reactions and mechanisms within the course. Only six out of the 26 students I interviewed created their own summary tables to organize the information to be learned for the second midterm. These students found great value in being able to assimilate the information into a coherent picture (see Appendix C for an example).

Alternatively, there were students who found the summary table template provided by the instructor as too complex. One student even mentioned not understanding how to create or use a summary table: “Yeah. I have a really hard time with summary tables. I’m really not sure what they’re supposed to be doing. Like I haven’t really done anything.” [Student 21, Interview Transcript]

Almost all students did appreciate and engage with a summary table the instructor used within lecture to organize the various reactions for nucleophilic acyl substitution. Students could refer to and complete the table while watching the pre-class videos and when solving problems in lecture. Yet, when I asked students if they had completed the table, most had not, but mentioned they would prior to the final exam.

> I think [summary tables] are really good. I haven’t done the nucleophilic acyl substitution table yet but I’m going to do that. I think it’s really good. Because when you think about nucleophilic acyl substitution and have about 5 videos on it, it can seem overwhelming. But if you break it down into that table, I think it’s fine. [Student 5, Interview Transcript]

When I asked students about working with their peers in class, the responses were split. Fourteen students mentioned solving problems with their peers in class and saw a lot of value in working with together. Students expressed that it was a great way to recall information and that through this process, “you get to know your strengths and weaknesses and you can teach each other what you know and what you don’t know.” [Student 3, Interview Transcript]

Six of the students did not know others in the class and admitted to working on their own throughout the semester, while another six students said they would work on their own and then check their answer with the person sitting next to them. This group of students who mostly worked independently admitted trying to talk with their peers, but at times found it was difficult to engage the person in conversation.

> I feel like it honestly depends on where you sit. Because I feel like a couple of people were really into the class and then would discuss things with you. But other people I would sit beside would be completely out of it and then didn't watch the videos so they were just sitting there to get answers. So sometimes it honestly just depends on where you sit. So I put somewhat useful because it wasn't useful all the time. But when I was discussing with people who watched the video, that was really helpful. [Student 16, Interview Transcript]

Out of class or external learning resources.

When discussing out of class or external learning resources, most students talked about their perceptions of office hours, the textbook, and Piazza, the online discussion forum. While most students thought going to office hours would be a good resource for their learning and to discuss specific questions/concerns, few actually did. Five students actually mentioned that while the instructor was really compassionate and funny, they were nervous about going to talk to her face to face. "For some reason I'm really intimidated by offices hours. I don't know why, I get stressed out, [so I didn't go]." [Student 4, Interview Transcript]

I was also surprised by the number of students who did not even know about the virtual office hours or that they were archived on the Connect course website. Out of the 26 students I interviewed, only two actually attended the "real-time" virtual office hours with another two referring to the archived videos. Despite this low number, there were a few students who used and appreciated this resource. For instance, one student mentioned that, “I went to office hours if I had questions and Piazza is helpful to go through and see what people are asking. Because sometimes you don’t know what you don’t know” [Student 23, Interview Transcript].

Four students commented on the usefulness of Piazza as a means for them to ask questions about problems or concepts they were confused with, and as an opportunity for them to provide feedback to their peers.

> Because you’re kind of teaching other people. And if you’re able to teach other people you should be able to do it yourself. I was reasoning through things and would be like – oh that’s a good question – and then I would go and do some reading and search for the answer. And doing that made me sure I wouldn’t make that mistake. And it really helped when [the instructor] would endorse it. So I would know it was correct. I found Piazza very useful. [Student 19, Interview Transcript]

Three students mentioned that, instead of using Piazza, they were part of a CHEM 200 Facebook group. Within the group, students would ask and answer questions primarily about the problem sets and practice midterm exams. This was an external resource that students created themselves in order to improve their learning of the course material.

About 10 students mentioned creating study groups closer to midterm exams in order to better understand the material. These students felt that working with others kept them motivated and helped to reason through their difficulties with particular problems or concepts.

My study group. It is really helpful. It’s just like – I don’t know how to word it. I guess…it’s interesting and helpful to see how other people approach certain questions. So you might not see how they approach a question if you weren’t in a group. So you don’t get stuck in a closed box of thinking and you get other perspectives of what you could have done. And I think that’s really helpful. [Student 16, Interview Transcript]

One animated student described how his study group had created a charades game in order to help them distinguish reactions based on given properties. This student said about group work:

It’s kind of like peer pressure when you work with other people. Like I don’t want to show how stupid I am. So you do your best to squeeze that brain juice and there’s also that – you want to contribute to it. And it’s like – hey team effort – high five guys. Like you want to do that. That’s why I’m really motivated to do it. And you can’t get too many laughs by yourself. But when you can make something fun, it’s much more bearable. [Student 2, Interview Transcript]

However, over half of the students did not participate in study groups as they felt they were easily distracted by others and would lose focus. Four students cited not knowing anyone in the class as the reason they were not part of a study group: “Would have been nice to bounce ideas off of someone but I didn’t know anyone in the class” [Student 20, Interview Transcript]. Most students saw the benefit of working with others, but the effort of actually arranging with other students and fitting it into their already busy schedule were common reasons for students not taking part in a study group.

Finally, students discussed minimal use of the textbook to guide their learning as the problems within it were basic in comparison to questions they would be ask on their midterm and final examinations. There were four non-native English speakers however who found the textbook extremely useful. It helped to provide the appropriate language and grounding to understand the complex course concepts.

Discussions about the five SEMLI-S dimensions.

Midway through the interview we discussed students' results from the SEMLI-S or, if they had not completed the SEMLI-S, they were asked to comment on the five dimensions. All students were encouraged to talk about how they viewed their ability to connect with the material and to monitor, evaluate, and plan their learning, and to comment on how their awareness of their learning risks, control of concentration, and self-efficacy changed over the course of the semester.

Constructivist connectivity.

While about half of the students mentioned that they tried to connect the information they learned in class to their every day lives, only five of the 26 students felt they actually could connect the CHEM 200 content to their other courses or their lives. One student mentioned that the information was directly related to what they had learned in their analytical chemistry course and with understanding amino acids in their second year biology course while three students could see the relevance of the section on carbohydrates in CHEM 200 to their lives. Most other students saw little to no connection, with many feeling that the material seemed to be too specific and "nitty-gritty" to be applicable to their other courses and the "real-world": "I don't really think about the stuff we learn in class and my everyday life. It's too far-fetched of a connection" [Student 8, Interview Transcript]. Students mentioned that perhaps later on in their degree they would see value in learning the basics of organic chemistry, but at this point in time, it was separate from what they already knew and understood. Interestingly, four out of the five students who were taking the course for the second time expressed that, this time through, they were seeing many more connections with their other courses and the world around them.

Monitoring, evaluation, and planning; Learning risks awareness; and control of concentration.

Upon reviewing the interview transcript, I noted that a substantial amount of time was spent talking about how students studied and about their strengths and weaknesses as learners. The connections between students' discussions of their ability to monitor, evaluate, and plan their learning was closely tied to their awareness of their challenges as learners and to their levels of focus and concentration over the course of the semester. Due to the embeddedness of these metacognitive dimensions, I have chosen to discuss their relationship to students' experiences within one, and not three separate sections.

As mentioned previously, the first midterm was the first point at which students became conscious about the necessity for adapting and improving their study strategies. Students who had made significant changes to their strategies and grades after the first midterm attributed this change to suggestions provided by the instructor. Some of these included:

- Not just reading a problem or concept, but actually writing out the problem or concept and reasoning through the answer or ideas;
- Studying in small chunks more consistently throughout the term;

- Consciously practicing problems, seeking understanding rather than an answer;
- Evaluating their understanding by referring to the course learning objectives and to how they performed on in-class quizzes and Sapling assignments;
- Being aware of, and keeping a record of, the problems or concepts they did not understand, and asking a peer or the instructor to clarify it for them;
- Coming to class prepared by "making sure to watch the videos and to understand the material before comings" [Student 26; Interview Transcript]

A student who went from failing the first midterm to receiving a C- in the course described her change in the following way:

> The first midterm I feel like I didn't really focus on actually doing it…and then I didn't do so well so I changed my study habits to doing actual problems and… doing more practice problems rather than just looking at the answer or trying to do it in my head. I think that's the biggest change… So I guess I kind of evaluate myself on how… like how deeply I understand a couple of questions…Like – I would write down like 10 random questions and then evaluate myself on them. Like how did I do? I'd give myself a mark [Student 16, Interview Transcript].

Successful students were students who were not only aware of their weaknesses, but exercised appropriate strategies by controlling their concentration and monitoring, evaluating, and planning their learning.

> When I'm studying, I'm studying. Like unless I'm with someone else but 90% of the time I'm studying on my own. I'm usually really, really concentrated for about 3 hours max. I can tell when I love focus like maybe I start checking Facebook. I

concentrate well, but not for long, like 2-3 hours and then I need a break. And I feel like I get a lot done in those few hours. [Student 23, Interview Transcript]

Another student commented that, "I know the common misconceptions/mistakes – if I'm aware I make them or are not familiar with that mechanism and haven't practiced enough then I definitely write them down" [Student 1, Interview Transcript].

And, while students acknowledged the necessity of changing their approaches to learning, undertaking this task was a challenge for most of them. Only a couple of students I spoke with had ever received advice in their previous courses about how to study. For many students, studying and maintaining concentration in class were a challenge.

> I feel like being in my second year I should know how to study a little bit more but I feel like my study – like the way I study could improve a little bit. I'm still working on that overall. And not just in this course but in all of my courses. But… I think my like ability to… like I think I knew what I was doing wrong but it was hard for me to figure out how to improve it. And it took me a really long time to figure it out. [Student 17, Interview Transcript]

> I couldn't tell you [what's wrong with the way I study]. I study a lot. I clearly don't study effectively but I do study a lot. And… I just don't get the type of results that I want. [Student 7, Interview Transcript]

> I just think when I stopped listening in class and such I kind of felt like I wasn't as aware and in control. [Student 4, Interview Transcript]

Students who were aware that they needed to make and adapt plans for learning the material found following through on that plan was the most difficult piece: “I feel like I do evaluate and plan but whether I stick to the plan…well…you know. I found that I didn’t summarize it or organize it good enough. But I really need to stick to the plan” [Student 18, Interview Transcript]. Implementing change was difficult to accomplish within the timeframe of the course and in light of their other demands as a second year science student.

Self-efficacy.

Within the interview I asked each student how their confidence in their ability to learn organic chemistry had changed over the course of the semester and to comment on how they thought their confidence had influenced their learning and experience in the course. Students’ responses were insightful and provided raw glimpses into the important role of self-efficacy.

Five students explicitly discussed their overconfidence in their abilities at the very beginning of the course. They were coming into a new school year having learned from their mistakes and successes in first-year university and ready to tackle their second year courses. They would stay on track, study efficiently, and seek help from their peers and the instructor when confused. Unfortunately, after receiving their grade on their first midterm, this confidence dropped. One student mentioned that his overconfidence coloured his ability to acknowledging his lack of effective learning strategies and the necessity for keeping up with and practicing the material.

Ten students attributed the drop in their confidence as a mix of various factors including the course getting “harder and harder”, being discouraged by their low grades/performance, their ineffective study strategies, and attempting to balance the high demands of the course with the rest of their courses and responsibilities.

> But it's, yeah, it's definitely a bit disheartening. You know, because you always think that if you're moderately intelligent and you work hard enough that you can do it…And that's really my biggest issue. It's the effectiveness of studying. [Student 7, Interview Transcript]

> I feel a little bit like more uncertain than I usually do… It always feels like the question I'm doing is wrong. Because I don't know if it's going to do something weird. Like I have to consider whether the molecule is going to do something weird or having chirality centre…It makes me uncertain because there's so many things you have to take into consideration. [Student 15, Interview Transcript]

Fear of failure, or the realization that they might fail, was the driving factor for a couple of students' drop in confidence. One student expressed that, "by the end [of the semester] I was completely crushed" [Student 25, Interview Transcript], while another student mentioned that their confidence was "getting lower and lower as I get to the final because I'm afraid of failing" [Student 11, Interview Transcript]. These students were particularly discouraged because passing the course was dependent on their final exam score. They had to prove themselves on the final exam, but were not overly confident in their ability to do so.

Even the students with low self-efficacy realized the necessity to "believe in [them]selves". So while their overall confidence was low, they were confident they could put in the appropriate time and energy to do well on the final exam and pass the course:

"Like I definitely do not feel confident with a lot of the stuff… But I do feel like I'll be able to do well on the final but I have to work a lot more than I have been" [Student 4, Interview Transcript]. These students appeared to have adopted a "fight or flight" mentality: in in order to succeed, they needed to have confidence in themselves and their ability to learn the material for the final exam.

Students who were successful or who were able to improve their learning over the course of the semester advised incoming students to start the course with a positive attitude but to not be overconfident in their abilities. They felt that in this course it was easy to get swept up in the idea that you understood the concepts, but it wasn't until the first midterm that students realized their actual understanding of the course material. One student even mentioned that, throughout the term and at the time of the midterm, they were "trying to psych [themselves] into a positive attitude" [Student 13, Interview Transcript]. A couple of students mentioned the need for them to have a realistic level of confidence: not too high, not too low, but something that would help them to believe in their abilities and to pick them up if they did not do well. A student sums up self-efficacy in this course by saying:

> I think confidence is a huge thing in this course. If you don't feel confident you just end up second-guessing yourself and doing a question the wrong way. And if you are doing it right you keep thinking you're doing it wrong. And it can be really stressful and hurt your brain. But having the confidence to be like – yes, I know this is this. Saying "I know" is so important. And the more you do it the better you get at it [Student 24, Interview Transcript].

Summary.

The interviews provided a more detailed account of the catalysts influencing students' metacognitive transformations in CHEM 200 and provided an indication of how social interactions play out in students' metacognition and self-efficacy. Probing students' perceptions and accounts of the five SEMLI-S dimensions provided a rich description as to why students may or may not experience metacognitive transformation within a given semester.

4.5 Chapter Summary

The findings presented within this chapter provided a contextual, complex description of the possible catalysts influencing various students' metacognitive transformations and noted the similarities and differences existing within and between various students. The constant comparison and triangulation of the findings revealed major themes that addressed the research questions for this study, namely:

- Performance-based assessment techniques as the checkpoints for student progress and learning;
- The in/visibility of internal/external resources for metacognitive transformations;
- The mixed perceptions of the role of the social on student learning, metacognition, and self-efficacy;
- The similarities/differences existing among students' perceptions of personal and structural supports and barriers to their becoming metacognitive, confident learners.

A more thorough synthesis of these themes and their relationship to the research questions will take place in the following chapter.

Chapter 5: Triangulation & Synthesis

This chapter triangulates and synthesizes the findings that emerged from the SEMLI-S, classroom observations, midterm feedback survey, and one-on-one interviews. This synthesis attempts to provide answers to the research questions that frame this study. The first two subsections triangulate the data and explore the types and characteristics of catalysts influencing students' metacognitive transformations (research questions 1&2) and the role that the social plays within students' metacognitive transformations (research question 3). The final subsection offers a more coherent synthesis of the overall study and reveals the similarities/differences existing between students' perceptions of the barriers/supports to their learning, metacognition, and self-efficacy.

5.1 Research Questions 1 & 2

The data collection methods provided a clear description of various catalysts that could have and did influence students' dimensions of metacognition in CHEM 200. I have classified the variety of catalysts within two main categories for discussion: performance-based assessment techniques and in/visibility of internal/external resources for metacognitive transformations.

Performance-based assessment techniques as catalytic crossroads for reflection and metacognitive transformation.

Students engaged the most with the resources and/or testing that was tied specifically to their grades in CHEM 200 (see Table 4). In-class quizzes, the Sapling learning homework, participatory classroom activities, and the midterm examinations were what students described as opportunities to "show what they know" or to practice what they "know and don't know". Handelsman, Miller, and Pfund (2007) view this type of formative, ongoing assessment as a tool for students to evaluate their learning both individually and socially, and, as a result of this, "learning becomes a process of reflection and analysis with specific markers of achievement, rather than simply an end point and a grade" (Handelsman et al., 2007, p. 49).

While the intention of providing students with formative feedback measures throughout the term was to help them adapt/change their strategies to enhance learning and metacognition, most of the students used the feedback not as a means for evaluating their learning strategies, but as an indication of what content they should "study harder and harder". In class, the instructor both formally and informally encouraged students to use the formative feedback as information to help them monitor, plan, and evaluate their learning, however, in the interviews, many students admitted to disregarding this advice. Furthermore, many students thought it was "too late" to develop appropriate strategies to improve their performance and understanding.

Despite the positive feedback on these resources, the first midterm examination was the most significant catalyst influencing students to reflect upon their learning and for encouraging them to consider transforming their metacognitive strategies. It was a crossroads at which students either improved their strategies and performance, or began to fall behind and became "lost". One student mentioned the need for them to, "sit my butt down properly and actually try to absorb and understand the material rather than trying to memorize it" [Midterm feedback survey respondent].

This emphasis on the midterm is not surprising given that high stakes exams and grades are often a focus for many students (Seymour & Hewitt, 1997). English (2010) comments that the use of high stakes tests or assessments,

> runs the risk of accepting and defining learning only in terms of what can be assessed on a paper and pencil test...The means to assessment, and its inherent limitations, become the ends themselves and place a cap on the possibility of learning outside that which tests are assessing. (p. 103)

The fact that midterms had more weight on students' grades overshadowed the usefulness of the formative assessment and resources. Within the first six weeks of this course students were innately aware of what course content they did not understand and/or that they needed to exhibit a more focused, rigorous study plan, but it is was not until they received their first midterm grade that this awareness started to become more urgent and explicit.

> Even when I'm studying I go through it and I'm like "oh I can do this". And then I get to the midterm and I can't do it…I struggle with it because in high school I never studied for anything and once I got here I realized I had to study and I don't really know how. [Student 11, Interview Transcript]

> Yeah, [that midterm mark is] way below than what I expected. Because I was studying so hard, and I know they say quality over quantity with respect to study hours, and I thought I was studying quality hours. Like I thought I was putting in the right type of approach. But apparently not. [Student 13, Interview Transcript]

The SEMLI-S revealed that students' awareness of their learning risks and control of concentration was relatively high throughout the semester, but that students' perceptions of their ability to actually implement effective metacognitive strategies decreased. In other words, students realize the importance in transforming their metacognitive regulation, but struggled with undertaking this task.

For many students this struggle appeared to become increasingly intense as the semester continued. After the first midterm, students became overwhelmed with the increasingly difficult CHEM 200 content and the demands from their other courses. This “overload” as many students called it, caused their focus and engagement in the formative assessment and the in-class activities to wane; by the time the second midterm came around many students had not yet developed new, or adapted old, learning strategies to enhance their metacognition and performance. One student mentioned, “I tried harder for the second midterm and had a better plan, but I didn’t live up to it” [Student 12, Interview Transcript].

A few students also mentioned that the content for the first CHEM 200 midterm built on their knowledge from first-year chemistry and that “for the second midterm material it was like – bam! Here’s what you have to try to learn” [Student 26, Interview Transcript]. The complexity of the new material was discouraging for many of the students. So not only was the content perceived as more difficult, but students were also struggling with finding the time and energy to focus on how to develop and implement effective learning strategies. This increasing sense of being overwhelmed may also be attributed to why class attendance decreased over the semester. Potter (2013) comments that for many undergraduate students the, “workload in other courses was forcing them to neglect other courses - they were skipping readings, or just skimming, missing classes to work on their reflective questions. And they knew it wasn't long before their work in my courses suffered as well" (p. 6). Similarly, within the interviews, three students talked about missing CHEM 200 lecture in order to study for their other courses or because they were lost and fell behind with the material.

Students had a strong, almost emotional, reaction to their midterm scores and it was these grades that allowed students to speak more clearly about their confidence throughout the semester. Seymour and Hewitt (1997) discussed that “grades are not objective, neutral facts about people; they are labels to which people react emotionally, and in terms of behavioral and identity adjustments” (p. 107). The midterms in this course then acted as checkpoints for students to assess their confidence in their ability to learn organic chemistry. The SEMLI-S scores revealed an overall drop in students’ confidence in their ability to succeed in CHEM 200, and this decrease could be attributed to students’ discouragement with their performance and to the vast amount of course content. Many students commented on the need for more time to study or to adapt their strategies because the cumulative nature of the course and extent of content did not support a significant change for many students.

The data collection for this study occurred at the end of semester, but prior to the final examination. With the final exam being worth 45 or 51% of students’ final grades, students were aware of the necessity of exercising effective study strategies in order to experience an increase in their overall grade. While students who were at risk of failing the course were nervous and dreading the final exam, they also saw it as an opportunity to really “show what they know”. These students felt that despite their performance within the first three months of the course they could resolve their earlier challenges. It was within this period that students realized they needed to dig deeper and to find the confidence and belief that they could succeed; and they did. All students I interviewed, even those that were entering the final exam with a below 50% average, passed the final and the course overall.

To help others learn from their experiences, I asked the interview participants to suggest how the instructor could emphasize the importance of using the formative feedback assessments, rather than the midterm, as a catalyst for change. One student commented that:

> I guess…I just feel like students need to live in fear of the course. Like just listen to the prof. Like me included, I feel like everyone just really listens carefully to her right before the midterm to get the mark on the midterm. And then once the midterm is done we just zone out. So instead of telling people when the quiz is going to be – have a pop up quiz…And as bad as that would be. Like it would be horrible for me to go through it. I might be constantly on top of my game. That's the only way I guess. If people aren't willing to put in the effort or attention then…Yeah. Just scare people. [Student 16, Interview Transcript]

Five other students in the interviews and midterm feedback survey emphasized the need for the instructor to "scare" students more often. One student mentioned that the instructor could "videotape everyone coming out of the final with sad faces. That might help a little bit" [Student 17, Interview Transcript]. These students commented that pressure was what made them study and reflect upon their performance.

While scaring students is not the intention of the instructor, it leads me to consider how we might increase pressure/awareness without causing fear or anxiety for students. While the pedagogy is shifting to more active, learning-centered approaches, the assessment methods in CHEM 200 and more generally in undergraduate science (Sunal et al., 2009; Taylor et al., 2002) continue to put weight on positivistic, summative assessment methods. In the case of this study, the exam was worth over 45% and the midterms at least 15%. Increasing the weight of the formative assessment methods in CHEM 200 could entice students to prioritize the in-class quizzes and course activities/worksheets and to use the feedback gained from these assessments to inform and potentially change how they learn. Shifting the focus from performance-based assessments that focus on right/wrong to more low-stakes, learning-based assessments might help students to engage more fully with their learning. As per English and Larson (1996) there is a need to realign and evaluate the relationship between the curricular and pedagogical goals and how students are being assessed.

In/visibility of internal/external resources for metacognitive transformations.

While there was a surplus of resources offered both explicitly and implicitly within CHEM 200 to enhance students learning and metacognition, few students engaged actively with these resources. Several students were not even aware of or could not remember when the resources were discussed in class. Students appeared to appreciate the instructor's desire to help students understand how to learn the material, however they continually iterated feeling overwhelmed with all of the demands of the course and the number of available resources. Potter (2013) comments that courses emphasizing active, constructivist learning demand significantly more time and work for the students and that, with this increased responsibility, many students are likely to struggle with mediating their time and the available resources. One student mentioned that, "since I don't have enough time to use every single resource possible, it has been hard picking out the most effective study strategies for myself" [Midterm feedback survey respondent].

This was a common perception among students: although they knew the resources were there they did not know which to implement.

Most of the students remembered the instructor's study advice documents/activities but few could actually recall the suggestions or had used them. Students mentioned that it would take a lot for them to change their study habits because they were already "stuck in my own way" or would "revert to old habits". One student commented that:

> Like I was saying earlier, if someone could just kind of guide me, I know it sounds kind of arrogant, but I've never had serious problems studying, with anything. And for whatever reason I'm aware that there's something that doesn't click with me with regards to chemistry. It does require a different type of learning. You know it's not like my physiology where I can just look at the notes, understand them, and then regurgitate it for the exam. There's something that's just not clicking so I need to use a different strategy but I'm just not really… aware of what that strategy is. [Student 7, Interview Transcript]

This student was aware of the difference in studying for organic chemistry compared to their other courses and was seeking guidance. However, they admitted to rarely engaging with their peers, the instructor, or any of the available resources. While students were able to articulate the differences in learning content for different courses/subjects, they still struggled with identifying the appropriate strategies for learning organic chemistry.

The importance of adapting how students monitor, evaluate, and plan their learning was made most explicit within the study strategy workshops targeted to low-performing students after the first midterm. Within this environment students openly discussed the effectiveness of their strategies and realized that just “doing problems” or “reading the textbook” was too general a strategy; they were exercising surface rather than deep approaches to learning (Winne & Hadwin, 1998). The instructor and the students discussed how the learning objectives could be used as a framework to guide their learning of the various course topics. And while the majority of the students who attended the workshops found the activities useful and valued setting personal learning goals for the rest of the semester, there was no explicit follow-up with these students to assess whether they achieved their goals. I interviewed four students who had attended the workshop. One out of four students discussed it as a critical moment at which they changed their approaches to studying leading to a higher grade on the second midterm. The three other students did not change their learning strategies as significantly but they did start using the learning objectives document as a reference for studying.

Despite the usefulness of the CHEM 200 internal/external resources, the majority of students did not engage with or recall mention of these resources. To explore this in more depth in the interviews, I asked the students to suggest how the instructor might better present the resources so students actually engage with them earlier in the semester. All students found this a difficult question to answer. While some students mentioned they would want to hear the suggestions from a friend or a senior peer, one student commented that:

> I don’t know. It’s hard. I think you might just have to live it. I think the reason I didn’t do it, it wasn’t because I didn’t think it was a good idea or anything, I think it was just that I procrastinate. It wasn’t that I didn’t want to, it’s just that I didn’t get around to it. You know what I mean? [Student 4, Interview Transcript]

While several students did not engage with many or any of the resources, there were some who did. These latter groups of students were able to make changes to their learning strategies and to improve their self-efficacy and metacognition. These students emphasized the usefulness of the learning objectives to guide their studying and understanding, the office hours and online forums as means for discussion and synthesis, and problem-solving and group work in class to work through their difficulties with the material.

5.2 Research Question 3

Students' perceptions about the influence of social interactions on their learning were drawn from the qualitative measures of classroom observations, the midterm feedback survey, and the one-on-one interviews. The course was restructured from previous terms to remove pure lecture from the classroom and to have students work on worksheets with one another in class. Similarly to the philosophy of other flipped classroom scholars (Estes et al., 2014), this shift was made to maximize active learning in order to assist students in becoming self-regulated learners outside of class and to engage with their peers in class to enhance their knowledge and understanding. Throughout the entire semester, the instructor encouraged students to ask questions to one another, to reason their answers with one another, and to continue their conversations outside of class with one another.

The way in which an instructor communicates with their students can influence students' cognitive engagement and involvement in the class (Ambrose et al., 2010; Moore, Walsh, & Risquez, 2007). Students' perceptions of and interactions with the instructor played a significantly positive role in students' experiences in CHEM 200. One student mentioned that the instructor was the reason why her confidence had not decreased significantly over the course of the term. Even though she was discouraged and did not enjoy organic chemistry, the instructor made the course bearable and fun. All students in the one-on-one interviews expressed much gratitude and praise for the instructor and valued her positivity, efforts, and caring nature.

> I feel like [the instructor] really wanted people to do well. And that's a think I don't always get from instructors. I think they want to trick you…but you can tell that she wanted everyone to do well. And she even said that on the first day. [Student 11, Interview Transcript]

On the midterm feedback survey, over ten students commented about their appreciation for the instructor's desire to engage them in their learning and her willingness to help students. Students valued her effort in putting together the resources even if they did not engage with them. And despite many of the students having apprehensions about organic chemistry and the structure of the course, the classroom environment facilitated by the instructor, both inside and outside of the class, was regarded as an interactive, safe place for learning.

The energy within the CHEM 200 classroom was high, with many of the students engaging with one another and the instructor in any given class. These students appeared to be focused on the worksheet problems and often times the instructor had to stop the students from individual discussion in order to take up the question with the whole class. The midterm survey feedback revealed that about 60% of students worked with their classmates on the problems but only 35% of the students were fully engaged with the worksheet and their peers. While the classroom environment became a great place for discussion, questions, and clarification, not all students engaged fully with the worksheets or with their peers.

In the interviews, students who worked alone either did so because they liked to work on their own or because they did not know anyone else in the class. Furthermore, while students worked in class with their peers, most of them worked on their own outside of class. Within the midterm feedback survey and the interviews, five students actually talked about feeling “socially isolated” outside of the classroom. There was an extreme emphasis on the need for students to work with others, however, outside of class they often felt alone. This was especially apparent with respect to the pre-class preparation, “with the videos. It’s more like I’m learning on my own. And it’s hard I guess.” [Student 25, Interview Transcript]. Fourteen students on the midterm feedback survey echoed this comment and indicated that, with no official lecture in class, they felt they were responsible for learning all of the material by themselves and that the instructor was in class only to take up problems.

Overall, there were mixed views on the usefulness of working and studying with peers. Many students commented that others easily distracted them, whereas some students found the online forums and study groups as critical to keeping them motivated and on track in the course. Students who displayed metacognitive strategies often reasoned their understandings with the instructor or with their peers. While they may have studied on their own, they consistently checked what they did not understand with another person. Two students in the interviews also advocated for a healthy mix of both group and personal study, recognizing that there is a need to gain a grounding of the material on your own and to then reason and reinforce your ideas with others later on.

But for most students, learning and studying was a personal thing. While students were concerned with the course structure and the vast amount of material to learn, they often blamed themselves for not being able to learn the material. Students expressed that following and sticking to a plan was difficult, with one student mentioning that "It's me. Like it's really just me this semester. It's just me. I'm the problem" [Student 21, Interview Transcript]. Another student mentioned that "It's my personal learning and it's my own learning that I have to improve on" [Student 15, Interview Transcript]. While students saw the value in learning with others, they perceived their learning as stemming directly from themselves as learners.

When discussing the role of the social within their learning, students' views were complex. What students "know, feel, and value is a critical part of what they will come to know about science" (Taylor et al., 2002, p. x), and was embedded within social interactions with their instructor and peers. Some students were fixed on their learning of organic chemistry as a personal, individual endeavour while others considered working and discussing with their peers and the instructor as integral components of their learning. Students' reflections were a personal account of their experiences and learning, but I did not conceptualize this reflection as entirely individual or isolated. Yes, they held a personal view, but students' experiences and learning existed and exists within a classroom and within a world influenced by many other external, social factors. While I explored an individual case of students' metacognitive transformations, the experiences occurring in this situation were anything but isolated.

5.3 Research Question 4

While there were several notable similarities and differences among the students, the most apparent similarities/differences were between/within students who were metacognitive or exhibited metacognitive transformations, and students who struggled with adapting and developing appropriate strategies for learning. The following sections will explore these groups of students in more detail.

Organic chemistry as a new or foreign topic/course

The majority of the students in this course are second year biological science students who must take this required introductory organic chemistry for their degree. While students were exposed to organic chemistry within their first-year of study, this was the first time they were taking a strictly organic chemistry course. Many of these students described the topic and learning process of CHEM 200 as something entirely new or foreign to them. Within the interviews and the midterm feedback survey, 10 students mentioned that CHEM 200 was a “different kind of class” for them. For instance, students mentioned that “it’s a problem-oriented course rather than a theory-driven course” [Student 15, Interview Transcript] or that “you have to practice more in this course and I’m more of a memorize and then apply it kind of guy” [Student 17, Interview Transcript]. Students could draw parallels between the problem-based orientation of organic chemistry and their math courses, however they commented that organic chemistry was more complex than math as the former has so many rules and exceptions to consider when problem solving.

Students were more inclined to courses that they regarded as conceptually-based or more descriptive. Many of the students commented that they were used to biology or psychology classes where,

> It's more reading and understanding. That's the knowledge that you keep. It's hard for that knowledge to fade away. Because when you read it you understand it and it's done. With ochem, you read it and maybe understand a theory but then it's harder because you do more questions and it's question-based. [Student 22, Interview Transcript]

Students' predispositions to a particular subject and way of learning were constraining their ability to successfully adapt and develop new learning strategies. Laurillard (2002) states that "the entire pre-history of their academic experience up to the time of a learning session can affect what [students] do" (p. 28). While problem-based courses such as math, chemistry, and physics were a part of their education within high school and first-year university, the majority of students in this class still struggled with these courses and admitted a preference for "reading" or "conceptually-based" courses such as biology and psychology. Meredith and Redish (2013) discuss how cultures of a scientific discipline can differ dramatically and, as such, "biology students often bring to their classes disciplinary expectations that may complicate or even obstruct interdisciplinary instruction" (p. 42).

Furthermore, while students were concerned with the difficulty of adapting their strategies for organic chemistry, many were also concerned with not having the requisite knowledge to communicate within and about the course material. Griffiths (2002) states that:

> The task of learning science then becomes tightly linked to learning the language of science. Just as any language cannot be learned by simply knowing the terms and phrases, understanding science involves more than a surface-level familiarity with science vocabulary. However, this task of learning to speak the language of science is quite formidable, considering the emphasis often placed on vocabulary in science classes. (p. 70)

On the midterm feedback survey, seven students commented that one of their biggest challenges was not having enough of a proper foundation in organic chemistry prior to the course.

> The topic of ochem is new to me. Well, relatively. So it's hard to get the gist of something when you're not really fluent in it. You need to know the language of ochem and it's really hard. But…I'm happy when I realize – oh I actually learned this this term. I understand what acyl means now. And then when I re-read some old stuff from ochem it makes a lot more sense. It's a lot better. [Student 22, Interview Transcript]

Within the interviews, four non-native English speakers discussed their struggle with using and understanding the concepts in CHEM 200. These students however, found the textbook extremely helpful in providing a very basic, coherent description and explanation of both the concepts and the terminology. One student even said the course textbook was clearer than texts in their native language.

Low self-efficacy and students' assumptions of their learning/abilities can cause them to question their knowledge and abilities in understanding science (Anderson & Nashon, 2007). Some students noted that they themselves or their peers were not "naturally good in chemistry" [Student 2, Interview Transcript], that chemistry was a course they had struggled with both in high school and in first year of university. This was often accompanied by low self-efficacy and paired with a dislike for subjects such as math and physics as well. These perceptions, along with the reputation of the course, hindered many students upon their arrival to the course.

So when considering how to enhance students' metacognition and learning in organic chemistry, we must take note of students' prior knowledge and background in order to help support them in being able to engage with the language of the course. Furthermore, we should be cognizant of the fact that this course requires different strategies than students' more favoured biology or psychology courses. Asking students to compare how they would study for CHEM 200 and for one of their biology courses could offer a crossroads at which students could consider the importance of adapting their current learning strategies for improved success.

Studying hard vs. studying smart.

While many students were aware of their weaknesses and of their lack of concentration when studying, these students struggled with effectively monitoring, evaluating and planning their learning. Even when students were aware of their issues, implementing change was difficult as they weren't exactly sure what to do. To improve their learning one student commented that perhaps they should "try to study harder? Smarter?" [Midterm survey respondent]. Within the interviews, I spoke with eight students who, based on their grade going into the final exam, were at risk of failing and who, despite effort, were struggling with developing the appropriate strategies for learning. Two of these students admitted that this course was not a priority for them and that they were just trying to do enough to get by, but the other six students felt they were putting in a lot of effort yet were not seeing the results they desired. One student mentioned that "while I do study hard, I don't think I study smart" [Interview Transcript, Student 3]. These accounts reveal the important role that motivation, priorities, and regulatory strategies play within student learning; learning in this course was a complex endeavour influenced by several factors.

Students whose grades dropped from one midterm to the next further echoed this concern. When discussing the strategies they used for studying, most students admitted to not putting in enough time due to other commitments or demands, and most described rather general strategies such as "doing a ton of problems", "reading the textbook", and "watching the videos again". These students, along with most students in the study strategy workshops, exhibited surface approaches to learning that do not take into account specific metacognitive strategies for enhanced learning (Winne & Hadwin, 1998; Winne & Nesbit, 2009). It was rare that any of these students used tables to summarize the various reactions, made a study plan to organize their time, monitored "what they know and do not know", evaluated their learning progress within test like conditions, or engaged with the instructor or their peers outside of class. Despite the instructor suggesting these strategies and providing multiple opportunities for students to reflect on their learning, students had difficulty in acknowledging, recognizing, or implementing this advice. Most had never received explicit advice before and some even mentioned that despite writing down the advice they were "far too lazy to change" [Student 2, Interview Transcript]. With learning strategies not taking a primary role in their previous and current education, it’s not surprising that students found it difficult to implement appropriate strategies for learning.

Students acknowledged having metacognitive experiences of being confused or concerned with their learning in CHEM 200, but they did not exercise the appropriate metacognitive knowledge or regulation to enhance their learning. Students’ demonstrated only surface knowledge about themselves as a learner, the demands of a particular task, and the strategies required to achieve this task (Flavell et al., 2002; Zohar & Barzilai, 2013). And most importantly, within this situation, students appeared to struggle most with their ability to plan, evaluate, and monitor their strategies for learning. Despite being in their second year, many students had yet to move beyond surface-like approaches to learning such as memorization and blanket reading. This group of students emphasizes the need for us to consider how we can best support these students who are entering CHEM 200 with low metacognitive knowledge and regulation.

Course lectures as both unhelpful and amazing.

Students’ feedback on the course content and structure was prolific and varied significantly. The flipped classroom approach was a relatively new structure for most of the students in this study. While the shift from a traditional to an active classroom occurred in order to enhance students learning and engagement, there was significant resistance and/or concerns from students about this approach. Within the flipped CHEM 200 classroom, students were responsible for watching a video and completing a quiz prior to most classes and were expected to come prepared to class for problem solving. This format was used to engage students with their peers and the instructor within a classroom environment in order to mediate students’ misconceptions and to work through difficult problems. While most students who actively engaged with the videos and quizzes were prepared to solve the in-class worksheet, this process was difficult for many. While over 85% of students on the midterm feedback survey perceived in-class group work as useful to their learning, many students were still apprehensive about the structure of the course itself. One student mentioned that the instructor was “doing an amazing job teaching the course”, with another commented that “I don’t find the lectures helpful at all”.

With the classroom being focused primarily on problem solving, students who were unable to watch the video or who did not fully understand the content mentioned feeling lost as there was little “real lecture” during class time. Students commented that “we’re expected to be experts” [Midterm survey respondent] upon entering the classroom and for many, putting in the time and effort before class was difficult. Estes et al. (2014) indicate that within the flipped classroom students are expected to “show initiative, be proactive, inquire, collaborate, and contribute to new knowledge in observable ways” - actions that undergraduate science student might not have much experience with.

Student concerns with the demands of preparing before class were apparent on the midterm feedback survey and as a result of these concerns, the instructor began most classes with a summary or activity reviewing the main concepts and mechanisms described in the video. This provided a bit more flexibility for students whose other responsibilities may have interfered with them watching the video. Over 20 of the students in the interviews acknowledged this change in structure and valued the instructor’s desire to improve how the course was taught.

One of the main criticism of the course however was that there was too much content to cover and to learn within the given period. Potter (2013) comments that, "the workload; what happens when students are presented with courses that make unreasonable demands on their time? They adopt a surface approach to their learning. They disengage with the ideas they are supposed to learn." (p. 6). The midterm feedback survey revealed that the sheer amount of content and keeping up with this content was students' biggest challenge to learning. And within the interviews, every student discussed having to put a significant amount of time and effort into the course if they wanted to be successful. Six students indicated that they were only taking four classes in order to be able to manage the demands of CHEM 200. Three of these students had been advised to do so by their friends, and three had failed the course previously so were aware of the difficulty of managing this course. The two most successful students I interviewed admitted that they spent anywhere from 8-10 hours a week outside of class learning the material, which is more than the typical six hours that most courses suggest (Potter, 2013). One of these students attributed her success to the sheer amount of time she spent learning the material. While students often do struggle with their ability and confidence in monitoring, evaluating, and planning their learning, this is even more difficult to accomplish with a heavy course load and workload.

Students' resistance to the flipped classroom approach acted as a barrier for student engagement both inside and outside of class. Within the interviews, three students were extremely vocal and negative about the move from a traditional lecture to a flipped classroom approach. They were adamant that they learned best through lecture and that the instructor needed to spend more time lecturing and less time taking up problems and walking around the class. In the midterm feedback survey fourteen students commented that they were the only ones teaching themselves because the instructor did not lecture. Estes et al. (2014) indicate that students who have not often been exposed to learner-centered environments are more likely to see the flipped classroom as "self-teaching" and struggle to see the value in this approach to teaching and learning.

Although there is value within these students' criticisms, their preoccupation or fixation on the course structure was preventing them from acknowledging or engaging with the benefits of this format. Within the interviews I reiterated the instructor's reasoning for this shift in the pedagogical approach and indicated that in previous terms, with a "lecture only" course, students often did not engage with problem-solving which is a key element in the course. I then asked these students how their strategies would be different if the course was lecture-based. All three students admitted that they would likely have come to class unprepared and they would have left the problem-solving until the last minute. This discussion is not to discredit students' concerns or suggestions about the course, but is to emphasize that dispositions as to how students believe they learn best can be difficult to overcome. While I do believe that the flipped classroom model is an appropriate shift for engaging students in their learning, I also agree that there are changes that can be made to the course structure in order to better prepare students for engaging with and learning the material before, during, and after class time.

However, for four out of the five students who were taking this course for the second time, the new flipped classroom approach was held in high regard. These students were adamant that this new format attributed to their newfound success in the course. The students praised the use of video lectures to help them gain an understanding of the material prior to coming to class, where they could now test their understanding. Despite many students' criticisms of the logistics of the new format, many others understood the benefits of this type of method. It forced them to review the material prior to lecture and to actually engage during class time with problems, activities they were not likely to do in their other classes or to do outside of CHEM 200 on their own.

Gaining an awareness of oneself as a learner.

This study also provided a window into how students were metacognitive or became metacognitive throughout the semester. Successful students exhibited specific, descriptive strategies of how they tackled the material in the course, with other students offering valuable advice or reflective accounts that could improve students' self-efficacy and metacognition in the course. This feedback from students offers a more contextual perspective of how educators might better support students in their journey as metacognitive, confident learners in CHEM 200.

Of particular interest in this study were the five interview participants who had previously failed the course. These students were not only able to offer insight into their current experiences in CHEM 200 but could compare it to their first time in the course. Their reflections revealed how they had become increasingly metacognitive in the year or two since they had completed the course. It was what I might call an intellectual and chronological maturity. One of the students' mentioned that,

> Well this semester because I understand the material a whole lot more I'm able to know what I don't know. I can tell you that my first attempt at chemistry, if I don't know something, I was completely unaware. I just wasn't getting it and everything was all like – gibberish. I guess it follows through with the process that I don't

know what I don't know, I know that I need to know, I know what I don't know, and hopefully you'll get to the next level where I grow and it starts to show. [Student 12, Interview Transcript]

Despite the fact that this student was not an "A" student, he was extremely metacognitive about seeking and implementing strategies that would help him to develop as a learner. He also admitted that doing this took time and, although he didn't prioritize this course as much as his other courses, he felt more prepared and confident this time around to tackle the challenges set out for him.

Four out of the five of these students also preferred the new flipped classroom approach as it engaged them as active learners both inside and outside of the class. When the course was presented in a traditional sense they would not prepare for class, lose focus in lectures, and rarely engage in problem-solving other than just prior to a midterm or final exam. The students emphasized the need for their peers to prepare prior to class and to actually engage with the problems in lecture. With respect to the carbonless copy paper activity that took place in class to test students' solving of reaction mechanisms, one student responded that,

> I think that last year I was just so confused and didn't feel confident enough that I could attempt them. Most of them were blank. But this year, I think I got most of them correct or at least half of the mechanism correct. Just because I think if you try, you can get a lot of the way and then once we go over it you can be like, okay, I did have the right idea there. And like, I was confused there and here's where I went wrong or what I should have done. Okay I was suppose to have gone that way. [Student 24, Interview Transcript]

This student displayed the appropriate metacognitive knowledge and regulation to tackle particular tasks. She was aware of her weaknesses, controlled her concentration in class, monitored and evaluated her progress, and demonstrated either confidence in her ability to succeed or and understanding as to why she may fail at a task.

These students, along with many of their peers, emphasized the need for students to actively engage in class and with their peers and the instructor. One student advised incoming students to,

> Listen to [the instructor] and do do what she is telling you to do. Like do watch all the videos, like do the practice questions, do listen to her advice. That's what I was doing at the beginning and it worked fine. [Student 4, Interview Transcript]

Students also encouraged others to pay closer attention to the instructor in order to be aware of the resources available to them. A student in the midterm feedback survey indicated that completing and reviewing all of the worksheet problems was really effective because, as the instructor mentioned continually, there were most reflective of what would be tested on an exam.

While the SEMLI-S revealed an overall drop in students' constructivist connectivity over the course of the semester, students who were successful in the course or who were taking the course for the second time, discussed the importance for students to seek connections between what they were learning in CHEM 200 with their other courses and the world around them. This connection was easier for students who were taking the course in their third year or above as many of their third and fourth year courses had explicit relationships with organic chemistry. It was harder for students in second year who felt the only major connections they could make were with select pieces of content from one of their second year biology courses. This finding emphasizes the need for more connections or authentic experiences to be presented through the CHEM 200 curriculum and pedagogy in order to enhance students' ability to connect the material with their courses and, more generally, the world around them.

There is also a need for students to recognize themselves as learners and as one student mentioned, "know yourself and what suits you best. And change it – experiment with it. Know how you study. Know that." [Student 2, Interview Transcript]. Another student also mentioned that despite his struggles in the course, it was a learning experience that would hopefully help him in future courses

> And I think it will help me in the future because in my third year I'm going to be taking harder courses. And in fourth year too. Figuring out what I have to do now for later. Making mistakes now will make my future courses better. [Student 17, Interview Transcripts]

Finally, one student mentioned that growth and confidence in learning occurs over time, and that as she continues with her degree, she is slowly starting to understand what university expects from her and slowly adapting from high school. This student, along with some of her more successful peers, displayed what Case and Gunstone (2006) would describe as emotional stability: in the face of pressure, these students were able to overcome or negotiate particular barriers that could inhibit their metacognitive development. As per Etkina and Planinsic (2014), "learning is a process of physical change that occurs in the brain, and possibly in the whole body" (p. 48). Metacognitive transformation is not immediate but a continual process within which students develop as metacognitive, confident learners.

5.4 Chapter Summary

This chapter answers the four research questions driving this study and provides a more comprehensive conceptualization of the types and characteristics of catalysts influencing students' metacognitive transformations in CHEM 200 and the role the social plays on students' learning, metacognition, and self-efficacy. This discussion reveals the complexity of students' experiences in CHEM 200 and the presence of several similarities/differences existing among different groups of students.

Students who entered the course with and/or who developed a metacognitive maturity over the course of the semester exhibited: a greater capacity to connect with the course material both inside and outside of class; descriptive, specific accounts about their knowledge and regulation of their strategies for learning; and an awareness of their strengths and weaknesses as learners. Most students in the course, however, were struggling to develop this metacognitive maturity. Students' preconceived experiences/knowledge and their lack of metacognitive regulation acted as barriers to productive metacognitive transformation. Their more novice and surface approaches to learning led them to fall behind with the course material and to disengage from or neglect both the internal and external resources targeted to enhancing their learning.

Many students acknowledged their own strengths/weaknesses as limiting or enhancing their learning, metacognition, and self-efficacy, but that the course pedagogy and curriculum also played a significant role. The majority of students discussed how the sheer amount of material to be learned, the fast pace of the course, and the new flipped classroom approach was difficult to mediate. The increasing push for students to become engaged, active learners was met with both resistance and difficulty and revealed the necessity for educators to reevaluate not only the CHEM 200 workload, but its relationship with students' course load and life balance.

Chapter 6: Conclusions and Implications

This study explored the types and characteristics of (social) catalysts that students perceived as influential to their metacognitive transformations in CHEM 200, an introductory organic chemistry course for biological science majors. Two sections of the course, taught by the same instructor, were the population of interest for this interpretive case study. The SEMLI-S survey instrument, classroom observations, midterm feedback survey, and one-on-one interviews offered an intimate perspective on how students' metacognition developed over the course of the semester. They also explored students' experiences within and perceptions of their learning in CHEM 200. Students' maturity as learners and the structure/demands of the learner-centered curriculum and pedagogy acted as both a support and/or barrier for their productive metacognitive transformations in the course. While successful students displayed a heightened level of metacognitive knowledge and regulation throughout the term, several students struggled with mediating and balancing the course demands and their learning strategies. This final chapter reviews the research questions in more detail and offers implications and suggestions for theory, practice, and future research.

6.1 Research Questions 1 & 2

This subsection addresses the following first two research questions:

1. *What are the catalysts for metacognitive transformation during one semester of an introductory organic chemistry course for biological science majors?*

2. *What aspects/characteristics of the catalysts do students perceive as most influential to their metacognitive transformations?*

These questions attempted to pinpoint the particular curricular and pedagogical catalysts that affected students' metacognitive transformation within CHEM 200, in addition to the catalysts students perceived as influential to their learning. The pre-post analysis of the SEMLI-S results revealed how students' dimensions of metacognition shifted over the course of the semester and acted as a reference for exploring their metacognitive transformations in CHEM 200. The results indicated that students were aware of their weaknesses/strengths as learners but that over the course of the semester, there was a significant drop in their ability to: constructively connect with the course material; monitor, evaluate, and plan their learning; and be confident in their ability to be successful in CHEM 200. The remaining data collection methods offered insight into why this drop may have occurred, but also gave witness to students who were able to enhance their metacognition and self-efficacy over the course of the semester.

An analysis and triangulation of the data corpus elicited general themes of the catalysts of students' metacognitive transformations. First and foremost, students engaged with and regarded the performance-based assessments as most influential to their learning processes in CHEM 200. Despite the usefulness of the formative assessment measures students regarded their performance on the first midterm exam as a crossroads at which they would reflect upon their learning strategies. This high stakes assessment overshadowed the earlier low-risk assessment techniques and was the critical point at which students explicitly questioned their experience and performance in the course.

Throughout the term the instructor also offered a variety of resources both inside and outside of class aimed at enhancing students' metacognition, confidence, and learning within the course. The analysis of the data corpus, however, revealed that only about a quarter of the students engaged with these types of resources. Students appreciated the instructor's provision of study strategy suggestions, activities, and workshops, but they admitted to not explicitly engaging with these resources. This was partly because they felt they did not need the help and partly because they were overwhelmed with the rest of their courses and responsibilities. Several students expressed being stuck in their ways of studying and that there was insufficient flexibility within the course to allow them to adapt their learning strategies.

The evaluation of the possible catalysts revealed students' perceptions of high stakes assessment as a means for studying, learning, and reflection. While there were ample opportunities throughout the semester for students to receive feedback on their learning within the course, students still held midterms as the most significant feedback on their progress. This is not surprising given that examinations in this course made up anywhere from 75-85% of students' overall grade. If this active, learner-centered classroom is meant to encourage students to become increasingly responsible, metacognitive, confident learners of science, the weight given to the low-risk formative assessment and the high-risk summative examinations should be redistributed (Sunal et al., 2009; Wieman, 2007). There is a need to "rebuild the infrastructure that will enable a fit between the academic values we wish to preserve and the new conditions for educating large numbers" (Laurillard, 2002, p. 4) (p. 4).

6.2 Research Question 3

This subsection addresses the following research question:

3. *To what extent do social dimensions influence the metacognitive transformations of students in an introductory organic chemistry course?*

This study revealed the complex relationship between students' perceptions of themselves as learners and the role that others played within their learning experiences. Observing the CHEM 200 lectures revealed an animated, interactive classroom where the majority of students worked on solving problems with their peers. This engagement, however, rarely translated to students' actions outside of the classroom. Only a handful of the students mentioned studying with their peers outside of class. Students' expressed that their coursework, commute, lack of preparation or concentration, and not knowing anyone in the course as limiting their ability to work with others outside of class.

When asked to provide advice for how future students could be successful in CHEM 200, most interviewees stressed the need for students to seek support from their peers and the instructor on a regular basis. While most students did not follow their own advice, they placed a significant value on their interactions with others. According to the students, these interactions challenged their understanding of the material and also encouraged them to reflect upon how they were planning, evaluating, and monitoring their learning. This examination of learning strategies was appreciated most by students who participated in the study strategy workshops. For many, it was the first time they had explicitly engaged with how they were learning and engaging with the material.

Many students attributed their interactions with the instructor, their peers, and tutors/teaching assistants as helpful for their learning, but most still described learning from an individualistic lens. That is, when it came to talking about learning, students often ascribed their own strengths and weaknesses as most critical to their performance and experience. Some students were confident in themselves as learners while others blamed their own inadequacies as the main factor impeding their metacognition, self-efficacy, and learning. Many students attributed their preconceived beliefs, knowledge, and experiences with teaching and learning at UBC and in high school as informing their approach to learning.

6.3 Research Question 4

The following research question is addressed in this section:

What do students perceive as the barriers and enhancers to their metacognitive transformations and how do these barriers/enhancers manifest during Chemistry study discourse?

Students' accounts of the external/internal interactions and resources on their learning progress exposed the catalysts that acted as both barriers and support to their metacognitive transformations in CHEM 200. The triangulation and synthesis of the findings revealed common trends existing among various students. For instance, as mentioned previously, many students discussed their preconceived notions of learning and their lack of prerequisite understanding of organic chemistry as barriers to their ability to become reflective, engaged learners in the course. These students entered the course with low self-efficacy and struggled in keeping up with the material and deciphering the appropriate resources to mediate their problems. In addition to this, many other students acknowledged their lack of efficient study strategies as limiting their ability to learn the course material. These students displayed surface strategies to learning (Winne & Hadwin, 1998) and despite the many resources provided by the instructor, were not able to abandon their poor habits.

External to their own abilities, several students regarded the course material, structure, and demands as overwhelming and difficult to mediate. These students discussed feeling discouraged by the fast-paced, cumulative nature of the course and that if they fell behind, it was difficult to catch up. There appeared to be limited flexibility within the course structure for students who lacked the sufficient metacognitive strategies and confidence to enhance their learning. Comparatively, there were students who appreciated the flipped, learner-centered classroom and who were able to mediate their learning by exercising effective metacognition strategies (i.e. planning, evaluation, and monitoring). This was especially apparent for students who were completing the course for the second time. This time around, these students were aware of their previous mistakes and appreciated that the course structure emphasized the necessity for preparation and practice prior to and after lecture. Overall, the successful students were aware of themselves as learners, were able to engage with or discount the usefulness of particular resources, worked with others, and continually regulated and reflected upon their performance in the course.

6.4 Conclusions

This study emphasized the important role of:

- High stakes assessment methods as critical catalysts for metacognitive reflection and potential transformation;
- The in/visibility of internal/external resources for metacognitive transformations due to the overshadowing of high stakes assessment methods;
- Students' perceptions of learning as a primarily individualistic experience within the active learning classroom;

- How student's background knowledge, their lack of effective study strategies, and the overwhelming course content can negatively influence their metacognitive transformations.

Within the CHEM 200 classroom, students' competencies and knowledge of effective strategies for learning, the course structure and demands, the instructor's characteristics, and the available peer supports outside/inside the course were all factors influencing how they engaged with their learning. This study exploring the (social) catalysts acting as support and barriers to students' metacognitive transformations in CHEM 200 at UBC revealed the complex relationships between teaching and learning in higher education. While successful students displayed productive metacognitive strategies, the majority of students in the course struggled with becoming metacognitive, confident learners. This latter concern may be attributed to students' lack of experience with reflective, metacognitive practices in their prior educational experiences, the overwhelming content and time pressures in CHEM 200, and the emphasis on summative examination-based assessment. Furthermore, "there is a range of broader personal and emotional issues that may have a noticeable impact on a student's ability to carry out the approach to learning that they see as optimal for their contexts" (Case & Gunstone, 2006, p. 64). While the findings of this study may not be directly generalized to other courses or institutions, it calls for science education and research that continues to question not only what students should learn, but how we can support students to become metacognitive, confident learners.

6.5 Implications

While implications have been subtly described throughout this thesis, this section will provide a more targeted description of how this study helps to inform theory, practice, and future research in teaching and learning in higher education and beyond.

Implications for theory.

This study will help to build upon past and current theories of metacognition, (social) metacognition, and metacognitive development. More specifically, this study provides insight into how learning and metacognition are perceived and negotiated by students within an active classroom. Laurillard (2002) and Taylor et al. (2002) view these classrooms as spaces in which students can create and value a collaborative sense of knowing within a discourse community. While students were an active part of the collective within CHEM 200, they often focused their learning on an inward locus. Students spoke about and appreciated the role of social interactions and environments on their learning, but their role as a learner appeared as the central component of their learning and performance in CHEM 200. With an increasing focus on learner-centered pedagogy and social constructions of knowledge in higher education, it is important to consider and evaluate how students perceive and balance this pull between individual and social learning.

This study also revealed the interplay between students' metacognitive knowledge, experiences, and regulation. Students' preconceived beliefs about learning and the demands of the course shaped their knowledge of themselves as a learner and their capability for success in the course. While students expressed an awareness of their difficulties as learners, the transition to more effective strategies for planning, evaluating, and monitoring their learning was problematic for many. My interactions with students revealed a disconnect between being metacognitive and understanding the required material. Within the context of high-stakes environments of introductory undergraduate science courses, the process of developing as a metacognitive learner then is not simple or linear, but complex and longitudinal.

Implications for practice and curriculum.

With respect to the pragmatics of curricular and pedagogical reform in science education, this study emphasizes the need for continued and ongoing evaluation and restructuring. Scholars of curricular and pedagogical reform in undergraduate science advocate for refocusing and reducing the course content on key ideas and to reevaluate their expectations of student responsibilities (Meredith & Redish, 2013; Redish & Hammer, 2009; Sunal et al., 2009; Wieman, 2007). While the CHEM 200 pedagogy and resources are moving in an appropriate direction for engaging students in their learning, the course content remains extensive. There is a need to reevaluate what content is most integral for these biological science students and to assess the amount of time and energy that is appropriate for students within the constraints of this course. We must also consider how this course fits within students' undergraduate science course load. As suggested by Meredith and Redish (2013), chemists teaching introductory courses should "work closely with biologists to learn not only what topics and habits of mind are useful to a biologist but also how the biologist's work is fundamentally different…and how to bridge that gap" (p. 43). Contextualizing and reducing the course load and demands on students may alleviate time pressures and allow students the opportunity to engage more fruitfully in class and with their learning (Meredith & Redish, 2013).

The reduction of content and placing more emphasis on formative assessment could alleviate students' fixation on examinations as catalysts for learning and engage students more fully in their metacognitive processes. Removing these shadows may assist students in appreciating how their learning strategies and confidence are either impeding or enhancing their learning. It may also engage students more actively in the course activities and resources geared towards enhancing their learning and metacognition. Successful students were witnesses to and examples of the importance of metacognition in the undergraduate science classroom and that we need to make this importance more apparent to the general population of students.

This study revealed the need to include students as agents of change in curricular and pedagogical reform and research. Students are key stakeholders in reform movements and as such, their opinions and experiences should be taken into consideration. They not only inform us of how teaching and learning is being perceived in the classroom but can offer constructive suggestions on how we can best engage students as metacognitive, confident learners. While many reform efforts have included student data in their research, it is critical to include students within the reform efforts beyond the classroom itself.

Implications for research.

This study emphasizes the need for continued research with regards to how educators may develop and enhance students' metacognition and self-efficacy within CHEM 200 and introductory undergraduate science courses in general. With respect to this particular case, I would be curious to investigate how a more distributed grading scheme of the course assessments might influence students' engagement with advice and activities designed to enhance their metacognitive knowledge, experiences, and regulation. I am interested in exploring how placing increased weight on pre-class preparation and low-risk formative feedback might transform students' metacognition and self-efficacy.

One of the most difficult questions for students to answer during the interviews was with regards to how the instructor could encourage students to implement her study advice and suggestions and to evaluate their strategies prior to the first midterm. Some students suggested the instructor scare them while others expressed that sometimes, a person needs to fail in order to see value in something. Experiencing a sense of fear or failure could be a huge setback for many students and as such, I encourage future research to design and assess novel curricular and pedagogical activities and interventions that assist students in understanding the importance of addressing their learning strategies. And furthermore, how such changes can influence a student's metacognitive development throughout their degree.

I would also advocate for research similar to that of Meredith and Redish (2013) and Redish and Hammer (2009) who for the past 10 years have been documenting the process of the development of an introductory physics course for biology majors. Course reform takes considerable time and effort and as such, it is critical to encourage educators to rigorously document and evaluate the challenges and successes of curricular and pedagogical reforms. Continual assessment within this realm will help to inform future practice and research in undergraduate science education that strives to engage students as metacognitive and confident learners.

6.6 Final remarks

This study provided a descriptive, holistic perspective of students' metacognitive transformations in a learner-centered introductory organic chemistry course for biological science majors. Throughout the completion and analysis of this work, I was able to learn both from students' successes and their failures. Students provided animated accounts of their challenges and victories within CHEM 200. While assessment methods, workload, and pre-conceived beliefs about learning played a significant role in limiting students' metacognitive transformations, students acknowledged the important role that their peers, the instructor, and they themselves played within their learning.

Despite the addition and presence of several resources to support students' metacognition, the presence of high stakes assessment methods (i.e. midterm examinations) overshadowed these resources and made them almost invisible to the majority of students. Further compounding this factor was that several students expressed their lack of effective study strategies and the overwhelming course content as limiting their ability to enhance and improve their learning. And despite this active learning environment, students continued to internalize their learning and worked primarily on their own. This study encourages us to consider how we might find a more balanced alignment between assessment methods, course demands, course resources, and student learning. We must not just add resources to support students' awareness of and strategies for learning, but must demonstrate the value of these resources by realigning course assessment methods and explicitly embedding these strategies for successful student learning within the course itself.

Reform efforts within undergraduate education are underway in order to engage students more actively in the process of learning science. However, we must also be cognizant that such shifts in curriculum and pedagogy can be overwhelming for both faculty and students. A classroom is composed of complex curricula, pedagogies, interactions, and people and as such, requires considerable attention. Studies, such as the one investigated in this thesis, act to inform the development of these reforms and to engage scholars and students in a collaborative discussion of how we might enhance learning, and more importantly, students' metacognitive transformations within the undergraduate science classroom.

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Appendix A

Literature Review Analysis

Summary of the research question(s), method(s), and stated or perceived paradigm for studies investigating metacognition and self-efficacy

Reference	Research Question(s)/Purpose	Method(s) Used	Stated or perceived paradigm	Comments
Allan & Clarke (2007)	• Exploration of variance in how first year undergraduate students experience the learning of generic, subject-related and metacognitive skills within a study skills module integrated into an education program.	• SWOT (strengths, weaknesses, opportunities and threats) analysis of the students in terms of the skills to be developed in the module • Written reflective accounts • Written student evaluations • Focus group interviews	• Case study undertaken from phenomenographic perspective • "Identifying the qualitative variation in the experience of learning study skills by first year undergraduate students" (p. 67)	• Purpose or research questions not explicit within the article • Unclear how they were assessing/conducting the SWOT analysis
Anderson et al. (2009)	• What is the nature of metacognition evident among students situationally interpreted across the learners' context? • How does students' metacognition change as their learning from field trip experiences is recontextualized in and beyond the classroom?	• Video recordings of students' experiences • Stimulated recall of the experiences in order to permit self-reflection on learning and metacognition • Semi-structured interviews	• Relativist-contextualist or qualitative-interpretivist • Acknowledgment of the complexity of the learning environment	• Explicitly state research questions and paradigm, epistemology, ontology framing their research/views • Emphasize for researchers to reflect on practices and methods used
Anderson & Nashon (2007)	• What metacognitive character in individual students and groups participating in an amusement park physics program are evident? • How are the individual and group metacognitive characteristics influencing and shaping knowledge construction?	• Metacognition Baseline Questionnaire • Field notes, video recordings of students, individual student voice recordings • Post-visit & post-activity interviews •	• Interpretive case study methodology • Epistemology/ontology view learning as occurring holistically, as a dynamic process, and as also occurring at the group level	• Explicitly state research questions, researcher paradigm, epistemology, and ontology
Cooper & Sandi-Urena (2009)	• Report on the development and validation of the Metacognitive Activities Inventory, an instrument designed to specifically assess students' metacognitive skillfulness during chemistry problem solving	• Metacognitive Activities Inventory • Expert perceptions • Factor analysis on student responses	• Positivist-decontextualist and/or empirical-analytic	• Discuss the need for instruments to "measure metacognition and related constructs in an easy, time-efficient, and reliable manner" (p. 241)
Duncan & McKeachie (2005)	• Review/discuss the Motivated Strategies for Learning Questionnaire	• Motivated Strategies for Learning Questionnaire	• Designed under social-cognitive view of motivation and learning strategies (view them as dynamic and contextually bound)	• Acknowledge importance of including behavioural observations

Reference	Research Question(s)/Purpose	Method(s) Used	Stated or perceived paradigm	Comments
Heikkila & Lonka (2006)	• Are students' cognitive strategies related to their learning approaches and self-regulatory skills? • What kinds of groups of individuals, who apply different strategies and approaches to learning, can be identified? • Are cognitive strategies, learning approaches and self-regulatory skills related to study success?	• Task Booklet of Learning • Strategy and Attribution Questionnaire • Personal journal writings • Course paper based on journals and course literature	• Positivist-decontextualist and/or empirical-analytic • The fluidity, dynamics of learning and students perceptions is not addressed	• Report that the use of the lack of a context-specific exploration was a limitation of the study • Although the research collected students' written reflection, this paper did not analyze these.
Lindstrom & Sharma (2011)	• Develop and evaluate a short, one-factor instrument for physics self-efficacy that would result in a single score per individual • Investigate physics self-efficacy of males and females with and without prior formal senior high school physics instruction across one academic year • Observe the relationship between physics self-efficacy and academic achievement at different times of the year	• Self-efficacy questionnaire	• Positivist-decontextualist and/or empirical-analytic	• Do not explicitly state paradigm, epistemology, and ontology framing their research • At the end of the article, they discuss that interviews with students would substantiate speculative ideas in the paper
Muis et al. (2010)	• What is the most adaptive classroom goal context (mastery, performance-approach, or combined mastery/performance-approach) for reducing anxiety and for promoting self-efficacy, cognitive engagement (e.g. metacognitive self-regulation), and achievement? • What influence does manipulating classroom goal structures have on student retention?	• Prior knowledge test • Patterns of Adaptive Learning Scales questionnaire • Self-efficacy, anxiety, and metacognitive self-regulation subscales of the Motivated Strategies for Learning Questionnaire • Raw scores measured student achievement	• Positivist-decontextualist and/or empirical-analytic	• Do not explicitly state paradigm, epistemology, and ontology framing their research
Nielsen et al. (2009)	• In what ways does student metacognition manifest while solving novel physics problems in both out-of-school and in-classroom contexts?	• Metacognition Baseline Questionnaire • Audio-recordings of students' conversations • Group problem-set worksheets • Follow-up focus group interviews • Stimulated recall	• Constructivist-interpretivist • Study was phenomenological and employed a case study approach	• Authors explicitly state their views of metacognition as dynamic
Peters &	• Explanatory mixed method study was	• Metacognitive Orientation Scale	• Constructivist-interpretivist	• Discuss the paradigm and

Reference	Research Question(s)/Purpose	Method(s) Used	Stated or perceived paradigm	Comments
Kitsantas (2009)	designed to show differences in content knowledge, knowledge of the nature of science, metacognition, and self-regulatory efficacy within and between the comparison and experimental group	(MOLES-S) • Metacognition of Nature of Science Scale • Self-efficacy for Learning Form • Test of Electricity-Magnetism Knowledge • Focus group interviews, think aloud protocols and work products to describe learning processes		epistemological/ontological views that frame the MOLES-S • Emphasis on differences between quantitative and qualitative methods
Rompayom et al. (2010)	• Develop an instrument in a set of open-ended question for assessing students' metacognitive ability concerning the knowledge of cognition in the scientific context	• Metacognitive inventory with seven open-ended questions about what students know about their own ideas, cognitive strategies, and when and why to use this strategy	• Relativist-contextualist	• Attempting to develop an instrument that captures students' context-specific perceptions in an open-ended format
Schraw & Dennison (1994)	• Generate and test an easily administered metacognitive inventory suitable for adolescents and adults	• Metacognitive Awareness Inventory • Compare two- and eight-factor solutions	• Positivist-decontextualist and/or empirical-analytic	• Do not explicitly state paradigm, epistemology, and ontology framing their research
Thomas (2003)	• Describes the conceptualization, design, and validation of an instrument for evaluating the metacognitive orientation of science classroom learning environments	• Metacognitive Orientation Learning Environment Scale – Science (MOLES-S)	• Social constructivism	• Explicitly discuss the paradigm and epistemological/ontological views that frame the MOLES-S
Thomas & Anderson (2012)	• Investigation of parents' metacognitive procedural and conditional knowledge to gauge: • What they knew about how they and their children thought and learned • Whether this metacognitive knowledge influenced their interactions with their children during their interaction with a simulation in a science museum	• Participant observations • Dyads' actions and dialogue with exhibit audio and video recorded • Interviews • Stimulated recall protocol	• Relativist-contextualist or qualitative-interpretivist • Interpretive methodology	• Discuss the paradigm and epistemological/ontological views that frame the research
Zusho et al. (2003)	• How does motivation change in chemistry over the course of one semester? • How does strategy use change in chemistry? • How do the motivational and cognitive components predict performance in chemistry?	• Administered surveys to collect info on students' goal orientations, self-efficacy, and task value beliefs, interest, anxiety, & cognitive and self-regulatory strategies	• Empirical-analytic but allude to importance of context	• Do not explicitly state paradigm, epistemology, and ontology but do talk about the importance of considering context within which the learning and study takes place

Appendix B

Interview recruitment letters and Consent documents

Appendix Includes:

- Email invitations
- Project letter of consent
- Interview letter of consent

E-mail invitation (for interviews)

Hi (name),

First off, thank you for filling out the CHEM 200 learning strategies survey in September and again last week. The surveys you have completed in CHEM 200 are helping me and (the instructor) to see how students' learning and feedback change over the course of the semester. This information helps us to think of ways to improve the course.

In addition to the surveys, I am asking students to take part in interviews to talk about your study strategies and overall experience in CHEM 200. It's a great opportunity to reflect on your learning throughout the term and to review your survey responses. The interviews will be held during the exam period (Dec 2nd-18th) and will be about 30-45 minutes long.

And - <u>you will be given $10 for taking part</u>.

If you are interested in participating, please e-mail me at welshash@interchange.ubc.ca

I will then contact you to arrange an interview day/time.

Confidentiality: Any of the information you provide during our interview will remain confidential. Professors will not have access to any individual comments and if the results are written up, a pseudonym, and not your real name will be used to protect your identity.

Thanks for your time!

-Ashley

PhD Candidate, Department of Curriculum & Pedagogy, UBC

THE UNIVERSITY OF BRITISH COLUMBIA

Department of Curriculum & Pedagogy
Faculty of Education
University of British Columbia
2125 Main Mall
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CHEM 200 Student Consent Form

Enhancing Student Learning and Performance in Undergraduate Organic Chemistry

Investigators:

Ashley Welsh (PhD Candidate)
Department of Curriculum & Pedagogy, UBC
Research Assistant, Carl Wieman Science Education Initiative
E-mail: (removed)

(Instructor)
Department of Chemistry, UBC
E-mail: (removed)
Phone Number: (removed)

Overview:
Embedded within CHEM 200 are several activities and workshops to help improve your learning of organic chemistry. Throughout the term, you will be invited to complete and submit surveys, activity worksheets, written reflections, and course/teaching assessment forms. We would like to use your feedback, work, and grades to analyze the usefulness of various activities and workshops on your learning. Your completion of this consent form indicates your approval for your data (i.e. feedback, work, and grades) to be used for analysis.

The findings of this project will be used to improve future iterations of the course. Conclusions may be published in some form and/or presented publicly, but without any information that could be used to identify you. The researchers will make any publications about the results of this study available to you.

Purpose:
The purpose of this study is to provide a more thorough understanding of how particular activities and workshops affect your learning of organic chemistry. Observing the class activities/workshops and collecting your in-class work, feedback, and grades will allow the researcher (Ashley Welsh) to provide targeted feedback to the instructor as to how they may teach more effectively.

Study Procedures:
Throughout the course you will be engage with various learning activities (e.g. workshops, worksheets, surveys, written reflections) that are aimed to help you learn organic chemistry more effectively. The workshops/activities may include an assessment of your perceptions of learning organic chemistry, how you study for the course, and the usefulness of these workshops/activities. Particular classes or workshops will be audio- and/or video-recorded to capture classroom engagement and discussion.

Potential Risks:
We do not think there is anything in this study that could harm you. However, if at any time during the course you feel uncomfortable and want to retract your consent, you may do this. All identifying information such as names and departments will be removed from any of your workshop/activity submissions. Pseudonyms will be used in place of names of people and physical descriptions of individuals will be altered or removed. During the semester, Jackie Stewart will not know if you have consented for

your data to be used for analysis. Your consent should not affect or alter your grade in this course. Ashley Welsh will be collecting the consent forms and will be the only person aware of who has provided consent.

Potential Benefits:
You might benefit directly from participating in and providing feedback for these workshops/activities. Your involvement/feedback will help you to become more aware of your learning and help you to seek out support that targets your academic needs or concerns. The benefits to you are also indirect; these observations are part of a major UBC initiative to improve science education. Your input is an essential component in understanding what educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.

Confidentiality:
Your confidentiality will be respected, but cannot be guaranteed fully in a group setting. The researcher (Ashley Welsh) will not be an instructor of any course in which you are currently enrolled. During the semester, Jackie Stewart will not have access to whether you did or did not provide consent for your data to be used for analysis. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet and your identity will not be available to any of your current instructors. The audio and video of the observations will be for analysis only and not shared publicly. 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.

Contact for information about the study:
If you have any questions or would like further information about this study, you may contact:

Ashley Welsh: (removed)

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 (phone number removed) or if long distance e-mail (removed).

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.

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

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

Department of Curriculum & Pedagogy
Faculty of Education
University of British Columbia
2125 Main Mall
Vancouver, BC Canada V6T 1Z4

Interview Consent Form

Enhancing Student Learning and Performance in Undergraduate Organic Chemistry

Investigators:

(Instructor)
Department of Chemistry, UBC
E-mail: (removed)
Phone Number: (removed)

Ashley Welsh (PhD Candidate)
Department of Curriculum & Pedagogy, UBC
Research Assistant, Carl Wieman Science Education Initiative
E-mail: welshash@interchange.ubc.ca

Overview:

You are invited to participate in an interview that explores how you went about studying for CHEM 200: Introductory Organic Chemistry at UBC. The interviews will engage you to reflect upon and discuss the strategies you have used throughout the semester to learn the course material. The findings of this project will be used to help CHEM 200 instructors to provide students with targeted advice for improving their study strategies and performance. Conclusions may be published in some form and/or presented publicly, but without any information that could be used to identify you. Any publications about the results of this study will be made available to you by one of the researchers.

Purpose:
The purpose of this study is to provide a more thorough understanding as to the study strategies students use to learn introductory organic chemistry (CHEM 200) at UBC. One-on-one interviews will be conducted with students to elaborate on how they have studied throughout the semester. The interviews will impart valuable insight regarding students' perceptions how they have studied and the perceived effectiveness of their study strategies.

Study Procedures:
Your participation will involve completing a one-on-one interview with a researcher (Ashley Welsh) to discuss the study strategies you used for CHEM 200. The interviewer will ask you to discus how you studied for CHEM 200, whether you perceive these strategies as effective, whether you made changes to your study strategies, and what advice you might offer to incoming students. You have the right to refuse responding to questions you are not comfortable answering. Typical interviews will last no more than one hour. An additional interview of 15-30 minutes in length might be required to ensure the researcher has accurately interpreted your answers. All interviews will be audio and video recorded. If you choose to complete an interview, you will be contacted via e-mail by a researcher to set up an interview time.

Potential Risks:
We do not think there is anything in this study that could harm you. However, if at any time during the interview you feel uncomfortable you can refrain from answering a question or may leave the workshop. All identifying information such as names and departments will be removed from any transcripts produced

as well as the final paper. Pseudonyms will be used in place of names of people and physical descriptions of individuals will be altered or removed.

Potential Benefits:
You might benefit directly from participating in this interview. After their analysis of the interview, the researcher might encourage you to seek applicable support services, which address your academic needs or concerns. The benefits to you are indirect; these interviews are part of a major UBC initiative to improve science education. Your input is an essential component in understanding what educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.

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 not be an instructor of any course in which you are currently enrolled. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet and will not be available to any of your current instructors. 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.

Remuneration/Compensation:
Upon the completion of an interview, you will be paid a monetary value of $10/hr with a half-an-hour minimum.

Contact for information about the study:
If you have any questions or would like further information about this study, you may contact the following researcher:

Ashley Welsh: (e-mail removed)

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 (phone number removed) or if long distance e-mail to (e-mail removed).

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.

*Please bring this signed consent form with you to your interview and present it to the researcher.

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

Appendix C

Data Collection and Analysis Documents

Appendix includes:

- COPUS Observation Protocol
- SEMLI-S Instrument
- Interview questions
- UBC Grading Scheme Conversion

Images of student work (summary

Classroom Observation Protocal for Undergraduate Science (COPUS)

1. Lec-Lecturing; FUp-Follow-up; RtW-Writing; D/V-Demo+; PQ-Pose Q; CQ-Clicker Q; R/H-Responding/help; 1o1-One-on-one; CD-Class discuss; AD-Admin; N-Nothing; O-Other
2. L-Listening; Ind-Individual work; Prd-Predicting; CG-Clicker Q discussion; WG-Worksheet group work; OG-Other group work; SQ-Student Q; WC-Whole class discuss.; SP-Student presentation; TQ-Test/quiz; W-Waiting; O-Other

For each 2 minute interval, check columns to show what's happening in each category (or draw vertical line to indicate continuation of activity).

CDOP version 5.1, Nov 22, 2012

5. What's happening - optional: add E, S, R, P, C, B, M, H, and/or O using the key

	1. instructor doing														2. Students doing													3. Engagement			4. Blooms			5. Hap	**Comments:** EG: explain difficult coding choices, flag key points for feedback for the instructor, identify good **analogies**, etc.
min	Lec	FUp	RtW	D/V	PQ	CQ	R/H	MG	1o1	AnQ	CD	AD	N	O	L	Ind	Prd	CG	WG	OG	SQ	AnQ	WC	SP	TQ	W	O	L	M	H	R/U	A/A	E/C		
0 - 2																																			
2																																			
4																																			
6																																			
8 - 10																																			
	Lec	FUp	RtW	D/V	PQ	CQ	R/H		1o1		CD	AD	N	O	L	Ind	Prd	CG	WG	OG	SQ		WC	SP	TQ	W	O	L	M	H	R/U	A/A	E/C	5. Hap	
10 - 12																																			
12																																			
14																																			
16																																			
18 - 20																																			
	Lec	FUp	RtW	D/V	PQ	CQ	R/H		1o1		CD	AD	N	O	L	Ind	Prd	CG	WG	OG	SQ		WC	SP	TQ	W	O	L	M	H	R/U	A/A	E/C	5. Hap	
20 - 22																																			
22																																			
24																																			
26																																			
28 - 30																																			

1. Lec-Lecturing; FUp-Follow-up; RtW-Writing; D/V-Demo+; PQ-Pose Q; CQ-Clicker Q; R/H-Responding/help; 1o1-One-on-one; CD-Class discuss; AD-Admin; N-Nothing; O-Other
2. L-Listening; Ind-Individual work; Prd-Predicting; CG-Clicker Q discussion; WG-Worksheet group work; OG-Other group work; SQ-Student Q; WC-Whole class discuss.; SP-Student presentation; TQ-Test/quiz; W-Waiting; O-Other
For each 2 minute interval, check columns to show what's happening in each category (or draw vertical line to indicate continuation of activity).

page 2

5. What's happening - optional: add E, S, R, P, C, B, M, H, and/or O using the key

	1. instructor doing														2. Students doing													3. Engagement			4. Blooms			5. Hap	Comments: EG: explain difficult coding choices, flag key points for feedback for the instructor, identify good **analogies**, etc.
min	Lec	FUp	RtW	D / V	PQ	CQ	R / H	MG	1o1	AnQ	CD	AD	N	O	L	Ind	Prd	CG	WG	OG	SQ	AnQ	WC	SP	TQ	W	O	L	M	H	R / U	A / A	E/C		
30 - 32																																			
32																																			
34																																			
36																																			
38 - 40																																			
	Lec	FUp	RtW	D / V	PQ	CQ	R / H		1o1		CD	AD	N	O	L	Ind	Prd	CG	WG	OG	SQ		WC	SP	TQ	W	O	L	M	H	R / U	A / A	E/C	5. Hap	
40 - 42																																			
42																																			
44																																			
46																																			
48 - 50																																			

NOTES

Learning Strategies Questionnaire

Name: ___________________________________ **Student Number:**_________________________________

Purpose: This questionnaire asks you to describe HOW OFTEN you do each of the following when studying for organic chemistry. There are no right or wrong answers. This is not a test and your answers will not affect your assessment. *Your opinion is what is wanted*. Your answers will enable us to improve future organic chemistry courses.

How to answer each question: On the next **two** pages you will find 30 sentences. For each sentence, circle only one number corresponding to your answer.

Questions	Never or Almost Never	Sometimes	Half of the time	Frequently	Always or Almost Always
1. I seek to connect what I learn from what happens in this course with out-of-class science (e.g. medicine, health, research)	1	2	3	4	5
2. I adjust my plan for a learning task if I am not making the progress I think I should.	1	2	3	4	5
3. I know I can understand the most difficult material presented in this course.	1	2	3	4	5
4. I am aware of when I am about to have a learning challenge.	1	2	3	4	5
5. I seek to connect what I learn from out-of-school science activities with what happens in the science classroom.	1	2	3	4	5
6. I plan to check my progress during a learning task.	1	2	3	4	5
7. I adjust my level of concentration, depending on the learning situation.	1	2	3	4	5
8. I try to understand clearly the aim of a task before I begin it.	1	2	3	4	5
9. I know I can master the skills being taught in this course.	1	2	3	4	5
10. I evaluate my learning processes with the aim of improving them.	1	2	3	4	5
11. I seek to connect what I learn in my life outside of class with this course.	1	2	3	4	5
12. I am aware of when I am about to lose track of a learning task.	1	2	3	4	5
13. I consider what type of thinking is best to use before I begin a learning task.	1	2	3	4	5
14. I am confident I can do a good job on the assignments and tests in this class.	1	2	3	4	5

Questions	Never or Almost Never	Sometimes	Half of the time	Frequently	Always or Almost Always
15. I seek to connect the information in this course with what I already know.	1	2	3	4	5
16. I am aware of when I do not understand an idea.	1	2	3	4	5
17. I consider whether or not a plan is necessary for a learning task before I begin the task	1	2	3	4	5
18. I adjust my level of concentration depending on the difficulty of the task.	1	2	3	4	5
19. I believe I will receive an excellent grade in this course.	1	2	3	4	5
20. I seek to connect what I learn from out-of-class science with what happens in this course.	1	2	3	4	5
21. I stop from time to time to check my progress on a learning task.	1	2	3	4	5
22. I am aware of when I have learning difficulties.	1	2	3	4	5
23. I am confident of understanding the most complex material presented by the instructor in this course.	1	2	3	4	5
24. I try to predict possible problems that might occur with my learning.	1	2	3	4	5
25. I seek to connect what I learn from what happens in the science classroom with out-of-school science activities.	1	2	3	4	5
26. I am aware of when I am not concentrating.	1	2	3	4	5
27. I assess how much I am learning during a learning task.	1	2	3	4	5
28. I am confident of understanding the basic concepts taught in this course.	1	2	3	4	5
29. I adjust my level of concentration to suit different science subjects.	1	2	3	4	5
30. I seek to connect what I learn in other subject areas with this course.	1	2	3	4	5

Semi-structured Interview Questions

- If someone were to ask you how your experience has been in CHEM 200 – what would you say?
- How have you kept up with the material over the course of the semester?
- How did you study for your midterms?
    - Do you have any good tips for incoming students?
    - Did your study strategies change from one midterm to the next or throughout the course?
- How did you prepare for the in-class quizzes?
- What was your biggest challenge this semester?
- How much of your mistakes on the midterms do to silly mistakes and how much was things you didn't understand?

SEMLI-S oriented questions

- How relevant is organic chemistry to your other courses? To your daily life?
- What has your confidence changed over the course of the semester?
- How do you evaluate your learning throughout the semester?
- How would you or did you improve your learning strategies?
- Are you aware of when you're having difficulties with your learning?
    - What do you do when having difficulty with questions/material?
- Do you notice when you lose concentration and how often do you lose concentration?
    - What do you to do address this?

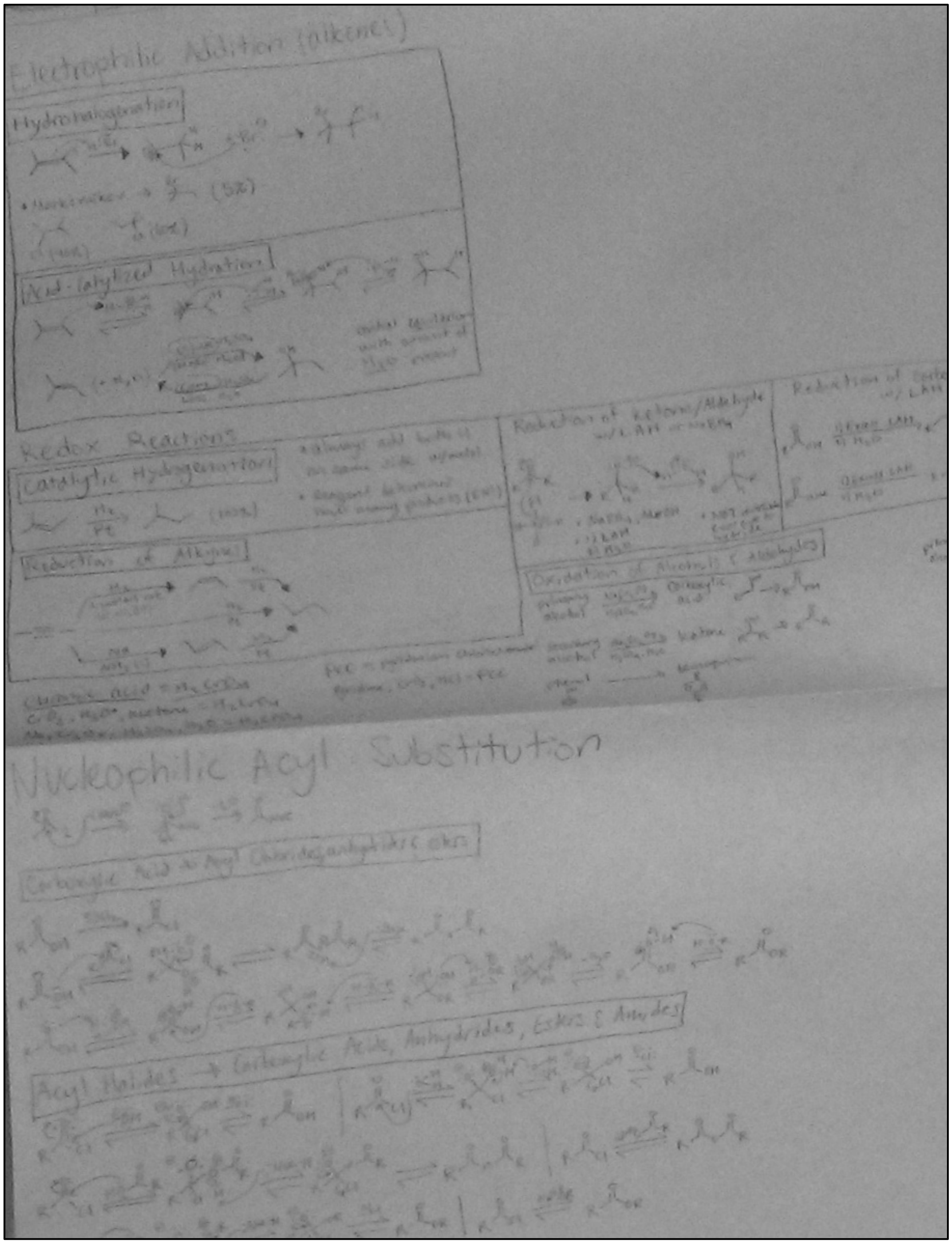
- How are you going to prepare for the final?
- Could you provide some feedback on: Carbonless copy paper activities; pre-videos and quizzes; in-class worksheets; resource centre; etc.
- What, if any, of the study strategies/resources provided by the instructor, did you use? How useful were they?
- Did you refer to the learning objectives when studying? Why or why not?
- How often did you work with other students? Why or why not?
    - How do you think your experience would be different it there was no group work in class?
- Did you attend office hours or go to the professor or TAs for help?
- If you could go back and take this course again, what would you do differently?
- What advice do you have for incoming students for how to be successful in CHEM 200?
- Do you have any additional feedback for the teaching team?

UBC Grading Scheme Conversion

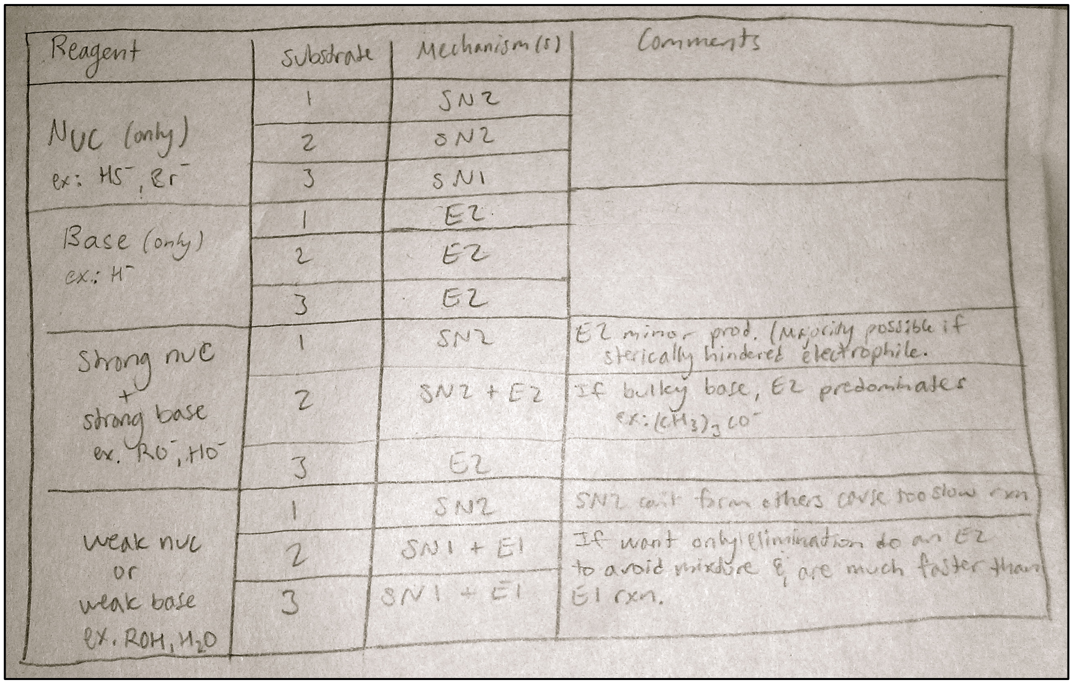
Percentage (%)	Letter Grades
90-100	A+
85-89	A
80-84	A-
76-79	B+
72-75	B
68-71	B-
64-67	C+
60-63	C
55-59	C-
50-54	D
0-49	F (Fail)

Images of Student Work

An example of how one of the interview participants used the learning objectives to guide their understanding and learning of the course material.



An example of a reaction summary chart created by one of the interview participants.



Reagent	Substrate	Mechanism(s)	Comments
Nuc (only) ex: HS^-, Br^-	1	SN2	
	2	SN2	
	3	SN1	
Base (only) ex: H^-	1	E2	
	2	E2	
	3	E2	
Strong nuc + strong base ex. RO^-, HO^-	1	SN2	E2 minor prod. (Majority possible if sterically hindered electrophile.
	2	SN2 + E2	If bulky base, E2 predominates ex: $(CH_3)_3CO^-$
	3	E2	
weak nuc or weak base ex. ROH, H_2O	1	SN2	SN2 can't form others cause too slow rxn
	2	SN1 + E1	If want only elimination do an E2 to avoid mixture & are much faster than E1 rxn.
	3	SN1 + E1	