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Understanding STEM Learning Outcomes Using A Phenomenographic Approach

Cheryl L. Brooks
University of Massachusetts Amherst

UNDERSTANDING STEM LEARNING OUTCOMES USING A PHENOMENOGRAPHIC APPROACH

A Dissertation Presented

by

CHERYL L. BROOKS

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirement for the degree of

DOCTOR OF PHILOSOPHY

September 2016

College of Education

UNDERSTANDING STEM LEARNING OUTCOMES USING A PHENOMENOGRAPHIC APPROACH

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DEDICATION

To my supportive, loving and patient family

ACKNOWLEDGEMENTS

This research would not have been possible without the guidance and support of many colleagues, friends and family. First, I would like to thank my advisor, Dr. Benita J. Barnes for her support over the past 8 years, and the other members of my thesis committee: Dr. Neal Anderson and Dr. Rebecca Woodland. Together, their feedback, insightful comments, and belief in my research inspired me to do my best work. I would also like to thank the McCormick family for their financial support and their encouragement to continue research in STEM education.

I would like to express my sincere gratitude to the friends and colleagues who have offered encouragement, advice, editing skills and insights on this research: Scott Auerbach, Surita Bhatia, Letha Gayle Brissett, Jackie Brousseau-Pereira, Sally Darby, Dan de la Torre, David Ford, Jody Goodman, Caroline Goutte, Kelly Gray, Roger Grette, Kelly Keene, Bill Leonard, Mike Malone, Julie and Mickey Marcus, Deb Napier, Claire Norton, Kathy Rubin, Tamara Sobers, and Phil Westmoreland. This is a better thesis because of each of you.

It is with deepest gratitude that I acknowledge my family: Greg, Collin and Spencer for their unwavering support of my goal to further my education and their encouragement to push forward in the darkest hours. I simply could not have completed this program or this dissertation without their patience, insights, suggestions, taking on of household chores and especially Spencer's transcription and editing skills.

Finally, I would like to thank the participants who openly and passionately described their perceptions on how they learned the skills and competencies necessary to be successful STEM professionals. I am forever grateful to them for sharing their stories.

ABSTRACT

UNDERSTANDING STEM LEARNING OUTCOMES USING A PHENOMENOGRAPHIC APPROACH

SEPTEMBER, 2016

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Today's STEM professionals are called upon to meet the nation's technical challenges with innovative technologies that push the boundaries of our current understanding and practices. While the total number of STEM graduates may be sufficient for the number of STEM jobs, many lack the specific competencies needed for practice, suggesting that science and engineering graduates may not be adequately prepared for careers in the STEM fields (U.S. Joint Economic Committee, 2012).

Using a phenomenographical approach, the researcher interviewed 18 STEM professionals to understand the qualitatively different ways in which they gained the technical and professional competencies needed to be successful engineers and scientists. As students, each of the participants in the study participated in some type of experiential learning such as a problem-based learning class, makerspace, internship, or research. The study utilized Experiential Learning Theory and Social Cognitive Career Theory as the theoretical frameworks. The study did not directly assess the four stages of Kolb and Fry's Experiential Learning Theory (Kolb & Fry, 1975), however, the analysis of the interviews confirmed that hands-on experiences result in improved technical and self-directed learning skills as described in the literature.

Results of the study indicate that a wide range of relevant, hands-on experiences can improve a student's ability to use math, science and engineering principles, problem-solve, and locate, organize and analyze data from multiple sources. In addition to internships, these types of experiences can take a variety of forms such as problem-based learning courses, makerspaces, research projects, design projects, and student clubs. However, the study also shows that some knowledge, skills and behaviors are only gained in the workplace or from background, contextual influences such as parents, siblings, sports teams, or scouts.

Social Cognitive Career Theory contributed to the understanding of how participants learned the skills and competencies needed for practice. While useful, this model was insufficient and results of the study led to the development of a three-phase Social Cognitive Experiential Learning Model that describes how learning environments, types of problems, and interactions with others contribute to the learning process. Results of the study have implications for both academia and industry.

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CHAPTER 1

STEM EDUCATION AND THE WORKFORCE

A. Introduction

Much of America's prosperity has been a result of innovative discoveries in science and technology, and the ability to convert those discoveries into functional products, processes, and services (National Science Foundation, 2010). However, business and government leaders warn that increased global competitiveness combined with reductions in the adequacy and supply of the workforce in the STEM (Science, Technology, Engineering and Math) fields has threatened our position as leaders of innovation in a knowledge-based economy (Business-Higher Education Forum, 2005; Business Roundtable, 2005; National Research Council, 2007). Secretary of Energy, Steven Chu declared, "We need engineers, we need scientists. This is at the heart of how the United States is going to stay competitive" (Science Insider, 2011).

However, there is a debate as to the nature of the STEM workforce shortage. Some analysts believe that deficits in both the supply and the proficiency of workers in the STEM fields have created a serious challenge in meeting the technological needs for economic growth and competitiveness (National Center on Education and the Economy, 2007; National Association of Manufacturers, 2005; National Research Council, 2007, 2010). Proponents of this view come from national agencies and industrial associations that claim that the American STEM workforce is lagging behind those of our foreign competitors (Butz, Bloom, Gross, Kelly, Kofner, Rippe, 2003). The problem is attributed to multiple factors such as insufficiencies in K-12 math and science preparation, low retention rates in post-secondary STEM education especially among women and underrepresented populations, and changes in workforce demographics (National Academies of Sciences, 2010).

Other studies suggest that the number of science and engineering workers is sufficient for the current economy (Charette, 2013; Salzman & Lynn, 2010; North, 2013; Salzman, Kuehn & Lowell, 2013; Butz, et al., 2003). These researchers argue that America has more supply of STEM graduates than demand for STEM jobs, pointing to data from the Bureau of Labor Statistics and to the Department of Education's projections for STEM degrees to be awarded between 2010 and 2020. Based on these data, researchers determined that the ratio of STEM degrees to job openings during the projected timeframe would be 1.55 (North, 2013; Salzman, Kuehn & Lowell, 2013). These analysts argue that companies perpetuate the myth that we need more STEM workers as a way to keep wages low and increase the pool of candidates (Charette, 2013). "In a classic economist's rebuttal to industry allegations of shortage of talent, the authors noted that had there been a genuine labor shortage, wages would have risen, but 'wages have remained flat with real wages hovering around their late 1990s levels'" (North, 2013, para. 9). Proponents of this view come from researchers including those at the RAND Corporation who claim that "neither earnings patterns nor unemployment patterns indicate an S & E [Science & Engineering] shortage" (Butz, et al., 2003, p. 3.).

The discrepancies between these two schools of thought seem to center around their differing definitions of a satisfactory STEM worker. While the total number of graduates with a degree in the STEM fields may be sufficient for the current number of STEM jobs, the number of STEM graduates with the specific competencies that industry needs is lacking, suggesting that science and engineering graduates may not be adequately prepared for careers in the STEM fields (Magee, 2004; Lattuca, Strauss & Volkwein, 2006; Ahn, Kwon, & Pearce, 2012; U.S. Joint Economic Committee, 2012).

B. Background of the Problem

In 2012, the Chronicle of Higher Education and American Public Media's Marketplace sponsored a survey of 50,000 employers to assess their perceptions of recent graduate's career preparation. Results of the survey indicated that the four top skills that graduates lack are: written and oral communication skills, ability to manage multiple priorities/adaptability, ability to problem solve, and ability to collaborate with others (Chronicle of Higher Education, 2012). According to the study, employers in Science and Technology had the most difficult time finding qualified recent graduates, more so than any other field (p. 51). They went on to say that internships, defined as practical training gained in the workplace, are the most heavily weighted attribute considered by employers. Industry representatives value internships for the skills students gain through hands-on experience, and recognize internships as a way of increasing the number of college students who enter the STEM fields (Dabipi, Dingwall, & Arumala, 2007).

In 2009, President Barack Obama outlined his Strategy for American Innovation (National Economic Council, 2009) that called, in part, for improving America's STEM education. One component of the strategy is to educate students with the 21st century skills needed to create a world class workforce (NEC, 2009). Obama created the Task Force on Skills for America's Future to address the skills gap and to build partnerships between businesses and educational institutions. At the 2011 meeting of the President's Council on Jobs and Competitiveness, 50 U.S. companies, including Intel, Facebook, and Caterpillar, committed resources to create thousands of internships for engineering students as a way to increase the supply of engineers into the workforce (Science Insider, 2011). Even with the commitment from these technical companies, however, the number of STEM-related internships is limited and highly competitive. While employers acknowledge the benefits student gain from hands-on experience, the insufficient number of available internships limits the number of students who may participate. Students need alternatives to industrial internships that provide the knowledge, skills and behaviors that may be missing in the traditional academic classroom.

Problem-based learning (PBL) is a type of experiential learning that is situated within the academic environment and includes group-based collaboration towards solving ill-structured, real-life problems. Developed in the 1960s in the medical community, PBL began as a way to prepare future physicians to think critically when solving real world medical problems (Major & Palmer, 2001). Studies of medical schools using PBL show that students in these programs were better able to use their knowledge to solve new problems, have somewhat improved clinical competencies, have better teamwork and presentation skills, and have a more positive attitude toward learning than those in traditional classrooms (Major & Palmer, 2001; Cockrell, Caplow, & Donaldson, 2000). Over time, problem-based learning expanded from the medical field to other fields including teacher education, social sciences, business, science and engineering (Savery &Duffy, 1995).

While studies indicate that students who participate in problem-based learning have improved skills compared to those in traditional academic classes (Chidthachack, Schulte, Ntow, Lin and Moore, 2013; Prince, van Eijs, Boshuizen, van der Vleuten, and Scherpbier, 2005), researchers have not examined how problem-based learning compares with industry internships. The current study will examine the perspectives of early career STEM professionals who, as students, participated in either problem based learning initiatives or internships in order to understand how these professionals believed they gained the competencies needed for professional practice. The implication of this study is that problem-based learning could provide an alternative mechanism for students to develop the technical and professional skills that are needed in the STEM fields.

C. Purpose

The purpose of this study is to explore the ways in which early career STEM professionals gain the knowledge, skills and behaviors needed for STEM practice. Specifically, the study will examine the perspectives of early career STEM professionals who, as students, participated in either problem based learning initiatives or internships in order to understand the qualitatively different ways in which these professionals gained the competencies they need to be successful engineers and scientists. The research is guided by three questions:

1. What are the qualitatively different ways that early career STEM professionals experience the central STEM learning outcomes in the workplace?
2. How did these early career STEM professionals, who as students participated in problem-based learning or in internships, gain these competencies?
3. What do these early career STEM professionals perceive to be the critical factors that contributed to their ability to develop the competencies necessary for STEM practice?

D. Theoretical Framework

Many studies have been done to determine how individual experiences affect the learning process, and what elements need to be present in order for genuine learning to occur (Kolb, 1975; Dewey, 1933; Borzak, 1981; Jarvis, 1995; and Schon, 1983). While traditional educational pedagogies were based on a behavioral approach, characterized by passive instruction, recent teaching styles incorporate a more comprehensive understanding of student learning that takes into account cognitive and social constructivist theories. This study is framed by two relevant learning theories: Kolb and Fry’s Experiential Learning Theory and Lent Brown and Hackett’s Social Cognitive Career Theory.

1. Experiential Learning Theory

Experiential learning can be defined as the process of gaining knowledge and making meaning from direct experiences (Itin, 1999). Unlike lecture-style instruction, experiential learning provides students with the opportunity to assume a more active role in the learning process. In this process, learning is cyclical: the individual is actively involved in a concrete experience and goes on to reflect and form generalizations about the experience that can be applied to future experiences (Kolb & Fry, 1975). “Knowledge results from the combination of grasping and transforming experience"(Kolb 1984, p. 41) and has its roots in both cognitive learning (Piaget, 1964) and pragmatism (Dewey, 1933). In the mid-1970s, Kolb and Fry created a model, known as the Experiential Learning Model, which describes how concrete experiences, observation, the formation of abstract concepts and testing in new situations constitute four distinct stages of learning (Kolb & Fry, 1975).

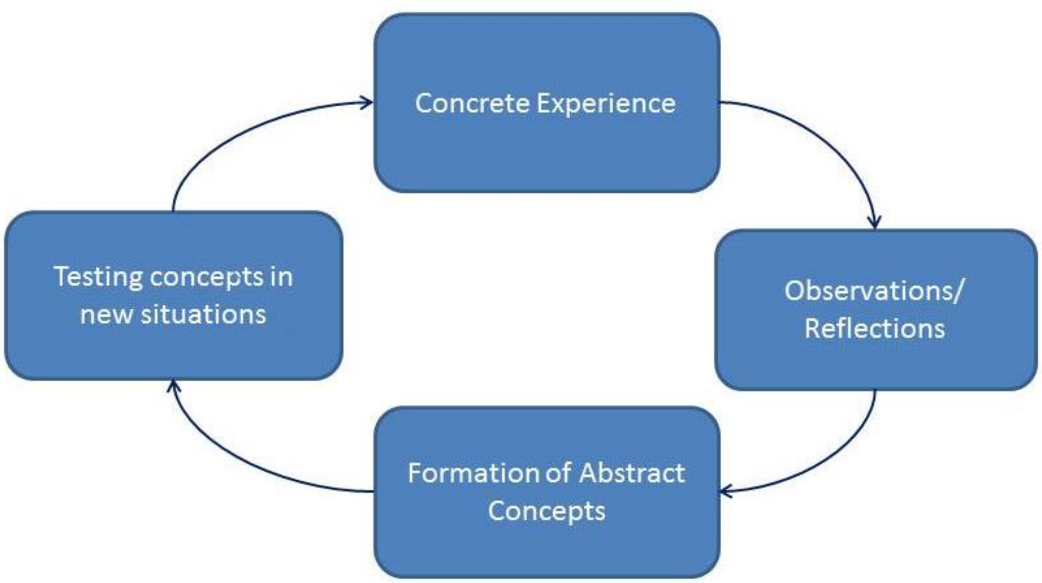

Figure 1: The Experiential Learning Model (Kolb & Fry, 1975)

The model seeks to explain how individuals learn through reflecting on experiences and making connections between observations and generalization of concepts in order to build understanding. They then go on to apply the concepts they learned in future experiences. This model has been widely used to inform practitioners, particularly in higher education. In a 1976 comparative study, Lee Harrisberger looked at different experiential learning programs within four national university engineering departments. Although the programs differed in pedagogical approaches, the overall effect was an increase in student confidence, and in problem-solving, organizational and interpersonal skills (Harrisberger, 1976). More recent studies have noted that experiential learning through design projects, internships, entrepreneurial and international experiences have resulted in improved creativity and innovation (Conger et al., 2010; Rampersad & Jarvis, 2013). Experiential learning spans a spectrum of hands-on experiences including workplace internships, community service, hands-on workshops, design projects, laboratory experiments, and problem-based learning. This research will focus on two types of experiential learning: internships and problem-based learning.

<u>a. Experiential Learning Theory: Application to Internships</u>

A wide range of programs go by the term “internship” within the higher education community. Some are paid while others are not. Some include varying levels of academic credit, some are relatively short, taking place during the summer, while others take place over the course of a semester or more. (These are generally referred to as cooperative education experiences and often contain specified learning goals). Common across all forms, however, is that internships provide students with the opportunity to gain knowledge, skills and behaviors through actual real-world experiences situated within the professional field. For students majoring in the STEM fields, industrial internships allow students to work alongside professionals and gain experience applying fundamental science, math and engineering principles to solve real-world technical problems. However, there is often variability in the nature and quality of the internship across individual positions or companies (Taylor, 1988; Jonassen, Strobel, & Lee, 2006; Samuelson & Litzler, 2013).

Little (1993) used Kolb's Learning Theory to provide a framework for understanding the experiences of technical communications majors during their internships. The study sought to make explicit the connection between theoretical principles learned in the classroom and skills used in professional practice. Little (1993) interviewed students, internship supervisors and academic program directors to gain insight into the nature of the internships including the type of duties the students performed, the academic courses that were useful during the internships, the type of oversight the students received during the course of the internship and the method of evaluation used to assess the students' performance. Results of the study indicated that there is a disparity between the students', supervisors' and program directors' perceptions of "job preparation and tasks performed in the workplace" (p. 435). Little (1993) argues that the experiential learning gained through internships helps to bridge the gap between what academicians believe to be the salient issues in a given field, and those that practitioners actually use. She goes on to argue that Kolb's Experiential Learning Theory provides an effective foundation for understanding how learning occurs through participation in concrete experiences combined with reflection and abstraction of ideas that are then applied to future experiences. The notion of both continuous learning and the ability to develop self-directed learning skills are key to Little's argument. She says, "The whole idea of Kolb's learning model—that is, experiential learning—is to ensure self-actualization. It affords students the opportunity to take charge of their own experiences, to accept the challenge of applying their academic knowledge to solving the problems posed by their real-world experiences" (Little, 1993, p. 444-445).

b. Experiential Learning Theory: Application to Problem-based Learning

Problem-based learning (PBL) focuses on exploring, understanding and solving relevant, realistic, ill-structured problems in collaborative groups (Barrows, 2000). Like internships, PBL uses real world problems as the foundation for learning. Unlike internships, however, PBL is situated within the academic environment rather than the work-place environment. The type of problem used in PBL can range in complexity, from relatively simple, yet realistic problems, to those that require more evidence or reasoning to resolve. Examples of the varying types of problems are story problems, decision-making problems, design problems, diagnosis/solution problems and dilemmas (Walker and Leary, 2009).

The PBL process begins with the presentation of an authentic problem that requires research, analysis, and synthesis of ideas. It is not simply applying knowledge gained from lecture, hand-out or homework set to a textbook problem (Mahendru and Mahindru, 2011). Rather, PBL aids students in their cognitive development by constructing knowledge based on evidence that is relevant to an actual, real-world problem.

In problem-based learning, students explore possible solutions through activities such as data collection, computer research, or lab work. Professors or tutors act as facilitators who guide the discovery process and help students reflect on the experiences so that they can begin to generalize the principles to the larger problem. The reflective component of PBL helps students to recognize that "knowledge is an outcome of a process of reasonable inquiry" (King & Kitchener, 1994, p. 71) that includes the synthesis of evidence and sound judgments that may alter as new information is gained (King & Kitchener, 1994). The students build upon their experiences as they go on to test their hypotheses in new situations.

c. Limitations of the Experiential Learning Model

One key component of PBL that is not explained through the Experiential Learning Model is the role that group-based collaboration plays in the learning process. Through group collaboration, students are introduced to new ideas and perspectives that often challenge their own. These alternative viewpoints provide a platform for testing currently held beliefs and encourage multiple perspectives on problem-solving. Students work together to construct a common direction for researching and solving the problem. Savery and Duffy (2001) noted that "collaborative groups are important because we can test our own understanding and examine the understanding of others as a mechanism for enriching, interweaving, and expanding our understanding of particular issues or phenomena" (p.2).

Similarly, a key component of internships is the development of working relationships with professionals in the STEM field. Supervisors often serve as mentors and provide feedback to students around skills learned in the workplace. In addition to being exposed to the scientific and professional environment, students often collaborate with other professionals in solving technical problems. The development of these professional, technical and problem-solving skills helps students to gain self-confidence and aids in the formation of their professional identity (Hunter, Laursen, & Seymour, 2007).

While the Experiential Learning Model provides an effective framework for understanding how internships and problem-based learning provide a mechanism for self-directed, reflective learning, it is insufficient in explaining the role that social constructs play in the learning process for STEM students. Social Cognitive Career Theory helps explain how interactions with others influences the learning process and aids in our understanding of the various factors that contribute to the achievement of learning outcomes.

2. Social Cognitive Career Theory

One benefit of experiential learning is that it provides students with the opportunity to practice specific skills and increase their sense of self-efficacy. Self-efficacy is the belief in one's capability to successfully perform a given task, and is a key construct in Lent, Brown and Hackett's (1994) Social Cognitive Career Theory (SCCT). The theory expands on Bandura's Social Cognitive Theory (1977), which emphasizes the roles of both cognitive and social processes on learning and behavior. Social Cognitive Theory suggests that individuals learn by watching and modeling others' behavior, and choosing to reproduce that behavior depending on the perceived rewards or punishments that are associated with the behavior (Bandura, 1977). According to the theory, the actual observed behavior, the environment, and the individual's cognition each contribute to the overall learning.

Lent, Brown and Hackett (1994) applied Bandura's theory to the area of career development in young adults. They developed a model in which "Person Inputs" such as race, gender, ethnicity, and disability status, along with previous experiences referred to as "Background Contextual Affordances" such as socialization, feedback from influential people, opportunities, and mastery of skills influence specific experiences. These factors go on to affect an individual's sense of self efficacy as well as their outcome expectations (Lent, et al., 1994; Allison & Cossette, 2007). Outcome expectations include a person's belief about the outcome of a specific task or performance. For example, a disadvantaged minority female growing up in an inner-city environment may have different beliefs and expectations about her career path than an affluent white male growing up in a suburban environment.

According to the model, self-efficacy and outcome expectations go on to affect a person's career interests, goal setting, and resulting actions, including their performance and persistence in career-related activities (Lent, et al., 2002).

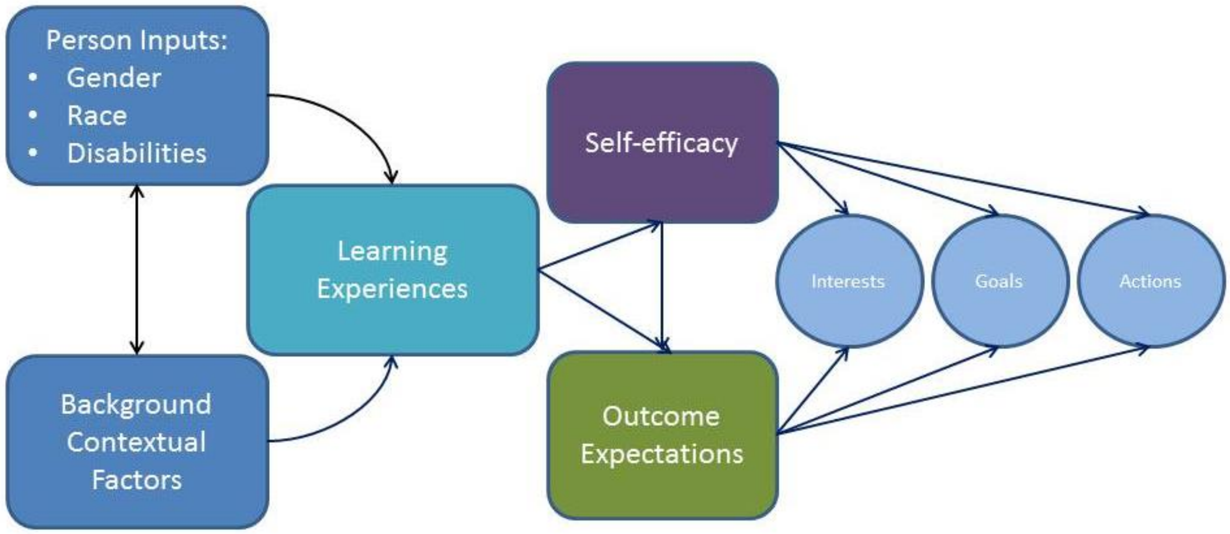

Figure 2: Social Cognitive Career Theory (Lent, et al., 1994).

The theory is important because it sheds light on the "key mechanisms by which people are able to exercise personal agency" (Lent, et al., 2002, p. 262) in the career decision-making process, and will help inform the current research in regards to the factors that affect the achievement of learning outcomes in experiential learning settings.

Researchers have used SCCT to help understand the pathways to STEM career choice, academic performance and persistence, and performance in the workplace (Lent, Brown, Schmidt, Brenner, Lyons, & Treistman, 2003; Lent, Brown, Sheu, Schmidt, Breener, Gloster, 2005). Luzzo, Hasper, Albert, Bibby, and Martinelli (1999) used SCCT to explain how personal performance in math and science activities along with vicarious learning enhanced students' interests and subsequent choice of major for STEM students. In a longitudinal study, Lent (2008), examined how self-efficacy, outcome expectations, interests, and goals affect persistence in first year engineering students. Results of this study suggested that self-efficacy serves as "precursor of outcome expectations, interests, and goals" (p. 333). The authors sought to examine the bi-directionality of the model: seeking to determine if pursuing one's interests, for example, would increase a person's self-efficacy. Results of the study, however, did not support this hypothesis. Rather, results indicated the unidirectional flow as indicated in the original SCCT model.

In 2011, Brown, Lent, Telander and Tramayne, conducted a meta-analytic path analysis to determine if SCCT could provide an effective theory for understanding work performance outcomes. The study examined the relationship between ability, self-efficacy, performance goals and work performance outcomes using eight meta-analyses published between 1984-2004 (Brown, et al., 2011). The performance indicators included performance ratings, job knowledge tests, productivity indices, and work-related simulations. Results of the study indicated that a modified version of SCCT that includes an added path from cognitive ability to goal difficulty provided the best fit for the data. According to the authors, this addition is tenable in that "persons with higher cognitive abilities tend to set more challenging goals for themselves" (p. 86-87). In addition, the data did not support the pathway from goal challenge to work performance when controlled for the effects of ability and self-efficacy. It was suggested by the authors that "goals [may] offer workers no unique motivational incentives that are not also provided by self-efficacy beliefs" (p. 88).

Taken together, Experiential Learning Theory and Social Cognitive Career Theory provide the framework for understanding the pathway by which STEM students achieve desired learning outcomes through the internship or problem-based learning environments. While the Experiential Learning Theory aids in our understanding of how students transform concrete experiences into a generalized knowledge through reflection and abstraction of ideas, SCCT helps explain the mechanism by which those experiences affect the student's sense of self-efficacy, outcomes expectations, and eventual performance.

E. Definition of Terms

Several key terms used throughout the study require definition.

Competencies-learning outcomes that are linked to workforce needs as defined by employers within the profession.

Early STEM career professionals-a person who has been working within the STEM field for five years or less. There is discussion in the literature about those who have STEM degrees and those who are working in STEM fields but do not have STEM degrees. For the purpose of this study, STEM career professionals have STEM degrees and are working in the STEM fields.

Experiential Learning Theory- theory developed by David Kolb that describes how concrete experiences, observation, the formation of abstract concepts and testing in new situations constitute four distinct stages of learning

Goal-setting-the decision to engage in a particular activity or the intention to proceed with a plan or course of action.

Learning outcomes-the particular knowledge or abilities a student should learn after a course of study or educational experience.

Problem-based learning- group-based collaboration attempting to solve ill-structured, real-life problems situated within the academic environment.

Self-efficacy-an individual's belief in their ability to effectively complete a task within a specific domain.

Skills-specific domain-related abilities that develop during the learning process

Social Cognitive Career Theory- theory developed by Lent, Brown and Hackett and highly influenced by Bandura claiming that in addition to the environment and background influences, people learn by observing others. These factors work together to develop a person's sense of self-efficacy and expectations that go on to affect their interests, goals and behavior, especially in regards to career-related matters.

STEM-Science, technology, engineering and math.

STEM co-op (cooperative education)-longer (usually six to nine month) industrial experiences within a STEM-related field.

STEM internships-short (usually three months or less) industrial experiences within a STEM-related field.

F. Summary/Significance of the Study

Many researchers have engaged in studies to identify key competencies that modern-day engineers and scientists need in order to be competitive in a global economy. While the number of STEM graduates exceeds the number of STEM jobs, a need still persists for entry level STEM workers who are better prepared for careers in the STEM fields, suggesting that there may be a gap between STEM education and practice. By focusing on the experiences of early STEM career professionals who, as students, participated in different types of experiential learning (internships and problem-based learning), this study will examine the variations in the ways that students gain the technical and professional skills and competencies necessary for STEM practice. The study will be framed by two important learning theories: Experiential Learning Theory and Social Cognitive Career Theory in order to understand the pathways that lead to achieving STEM workplace learning outcomes.

The significance of this study is twofold: first, by interviewing early career STEM professionals who participated in different types of experiential learning environments, we will shed light on the skills and competencies that are gained through internships and problem-based learning experiences vis-à-vis those needed for STEM practice; second, by understanding the mechanism by which STEM students gain these skills and competencies, we can provide educators insights into pedagogies aimed at achieving desired STEM outcomes for a broad range of STEM students.

CHAPTER 2

REVIEW OF THE LITERATURE

A. Introduction

Understanding what types of learning outcomes are necessary for STEM practice and the mechanism by which those learning outcomes are achieved is fundamental to uncovering why some STEM graduates are not prepared for STEM careers. It is important, therefore, to define what is meant by the term "STEM learning outcomes" and to understand how those outcomes are measured. Because internships are considered by STEM employers as the "gold standard" for gaining specific learning outcomes, it is important to understand what learning outcomes STEM students who participate in internships gain and the mechanism by which they gain them. Finally, it is important to understand the learning outcomes gained from problem-based learning initiatives and how they compare with those gained in internships.

The review of the literature will, therefore, include: a look at the term "learning outcomes" in general, and more specifically within the STEM fields, a review of how those outcomes are assessed, and a review of studies of the learning outcomes associated with both internships and problem-based learning. When possible, the review will also take into account the mechanism by which the learning outcomes were achieved. For example, if the internship acted as the vehicle for a student to learn how to collect and analyze data for an environmental impact assessment, one-on-one mentoring may have been the mechanism by which the student acquired the skill to collect soil samples and run the atomic absorption spectrophotometer.

B. Learning Outcomes

The notion of identifying learning outcomes for college students is not a new one. Educators, state and federal government officials, and industrial managers understand the need to graduate students with the knowledge, skills and behaviors they will need to be successful in the workplace and to be contributing citizens in society. However, agreeing on a common definition of learning outcomes and being able to measure them presents a challenging problem to educators. Many groups have undertaken the task of identifying those outcomes both from a broad educational perspective and through discipline-specific skills and competencies (Kuh and Ikenberry, 2009; Lang, Cruse, McVey, & McMasters, 1999, ABET 2014). Looking at the progression of identifying and measuring learning outcomes from an historical perspective helps to frame our understanding of how the term has evolved over time and what it means in a contemporary context.

1. History of Learning Outcomes in Higher Education

In 2005, Secretary of Education Margaret Spellings formed a commission to address how U.S. colleges and universities were preparing students for the 21st century workforce. The Commission published a report on the future of U.S. higher education that addressed issues of access, affordability, quality and accountability. The increased emphasis on accountability, in fact, stemmed from the other three issues. As the cost of attending colleges increased, stakeholders such as tuition-paying families, governing boards and taxpayers demanded that colleges and universities demonstrate that students were receiving a quality education and that "the institution is using its resources appropriately to help students develop the knowledge, skills, competencies, and dispositions required to function effectively in the 21st century" (Kuh, 2009, p.4). The commission recommended creating a nationwide database management system that could provide a vehicle for expressing student learning outcomes. Critics of this proposal argued that learning outcomes "…are highly contextual, and should be adapted or modified in accordance with local needs, issues, purposes, and concerns of stakeholders" (National Council of Teachers of English, 2009, Principles of Effective Writing Section, para. 3). Nonetheless, higher education associations encouraged institutions to voluntarily develop and assess learning outcomes for their students. Over time, many colleges and universities began to identify and report performance measures aimed at improving student learning outcomes.

In an effort to develop a more nation-wide consensus on specific learning outcomes necessary for the 21st century workforce, the Lumina Foundation, in collaboration with various stakeholders such as accreditation boards, national and international associations and councils, individual universities and colleges, and leading researchers in the field of educational outcomes, created a Degree Profile that outlines the learning outcomes necessary for college students at the associate, bachelor and master degree levels. They modeled the Degree Profile after the European higher education model known as the Bologna Process (Adelman, 2008).

The Degree Profile identifies a common standard of student work that includes performance measures for agreed-upon knowledge, skills and behaviors, and outlines specific competencies across five areas: broad knowledge, specialized knowledge, intellectual skills, applied learning, and civic learning (Lumina, 2011). For example, competencies for specialized knowledge include theory, methods, tools, and terminology relevant to the specific major or field, while broad knowledge includes an integrative range of study in science, social science, humanities and the arts, all within a culturally diverse perspective (Lumina, 2011). Competencies for intellectual skills include analytical inquiry, use of informational resources, quantitative and communication fluency and the engagement of diverse perspectives (Lumina, 2011). Applied and civic learning competencies integrate theory with practice and include research or field-based experiences. Civic learning contains an analytic and reflective component that leads to some measurable action such as a project, paper, exhibit or performance (Lumina, 2011). Authors of the Degree Qualifications Profile stress that competencies are defined “in ways that emphasize both the cumulative *integration* of learning from many sources and the *application* of learning in a variety of settings” (p. 2). As of 2013, approximately 300 higher education institutions were using or testing the Degree Qualifications Profile for their programs (Merisotis, 2013).

Although the entire U.S. higher education community has not embraced a common set of learning outcomes, it is clear that most colleges and universities are identifying student learning outcomes within their institution (Lederman, 2010). In a 2009 paper published by the National Institute for Learning Outcomes Assessment (NILOA), George Kuh and Stanley Ikenberry reported results from a national survey of 1500 high level administrators including provosts and chief academic officers. The study found that most colleges and universities in the United States identify learning outcomes for their students that include both program-specific and institution-level assessments (Kuh & Ikenberry, 2009).

While there is still no consensus as to which learning outcomes students need, educators understand that, “To succeed in the contemporary workplace, today’s student must prepare for jobs that are rapidly changing, use technologies that are still emerging and work with colleagues from (and often in) all parts of the globe” (Lumina Foundation, 2011, p.1). This viewpoint is particularly true for those students majoring in the STEM fields.

2. STEM Learning Outcomes

Learning outcomes for STEM majors include both discipline-specific and broad educational outcomes necessary for modern-day practice. While learning outcomes for individual STEM programs are adopted on a departmental level, there are some national guidelines, generally provided by professional societies and accreditation agencies, as to what students should be learning within the specific STEM disciplines. These guidelines ensures that programs are meeting a standard measure of quality across key areas such as facilities, faculty, student services, curricula, and student learning outcomes (Council for Higher Education Accreditation, 2010). Though similar, learning outcomes across Science, Technology, Engineering and Math do reflect differences in fundamental knowledge and application. Math and computer technology, for example, are hierarchical in nature, while engineering integrates knowledge of math and science into application-based outcomes.

a. Science

For the foundational sciences such as physics, chemistry, and biology, guidelines range from general to more rigorous, often as a result of the accreditation process. Physics, for example, does not have an accreditation program; however, the American Physical Society provides general guidelines that include both technical knowledge in core physics principles and math, analytical problem-solving, and communication skills such as technical writing and presenting (APS, 2014). Both chemistry and biology offer accreditation to their programs and, as a result, their guidelines are more rigorous. The American Chemical Society (ACS) states that "ACS-approved programs offer a broad-based and rigorous chemistry education that gives students intellectual, experimental, and communication skills to become effective scientific professionals" (ACS, 2014, p.1). In addition to articulating guidelines for curriculum, infrastructure and faculty, the ACS guidelines include expectations for professional skills including problem-solving, chemical literature skills, laboratory safety skills, communication skills, team skills, and ethics (ACS, 2014). Similarly, the American Society for Biochemistry and Molecular Biology provides guidelines for accreditation that include "a strong grounding in its core concepts" (ASBMB, 2014, para. 1) as well as critical reasoning, communication skills, and experiential learning, which includes laboratory experience, research, internships, or cooperative learning experiences. However, they are clear that the accreditation process is not prescriptive, but rather allows for individual programs to carry out their educational mission while being guided by overarching principles, stating:

> Since both our discipline and educational best practices are subject to continual change and innovation, the recommendation regarding curriculum … intentionally avoids providing a list of 'required' courses. Such a prescriptive, topic-based approach runs counter to ASBMB's desire to focus on outcomes as well as our intention to provide the members of the educational community free reign to apply their creativity and experience to the continual improvement of BMB pedagogy (ASBMB, 2014, para. 2).

b. Technology

The Association for Computing Machinery (ACM) takes a different approach to specifying the learning outcomes for students in the computer science, computer engineering, information systems and technology, and software fields. Along with the Institute for Electrical and Electronics Engineers (IEEE), they developed a 500 page document that outlines the specific knowledge, skills, and competencies needed in the computer and technology arena. They describe 18 knowledge areas known as the "Core Body of Knowledge" (ACM, 2014) as well as applications-based competencies such as problem-solving, integration of theory and practice, using a systems-level perspective, and broad applicability of computer and professional skills including communication, organization, and a commitment to professional responsibility and life-long learning. The recommendations draw from Bloom's taxonomy suggesting that student levels of learning move from lower order to higher order along three general areas: cognitive, affective, and psychomotor. Thus, many of the knowledge areas build upon the foundational courses toward more advanced concepts.

c. Engineering

The earliest engineers were trained through apprenticeships and much of the apprentice style of training remained in the early pedagogy of higher education (Hirleman, Groll & Atkinson, 2007). In the 1950s concerns for national security brought on by World War II and the launching of Sputnik shifted engineering education from a focus on practical training to a focus on research and the development of new technologies, especially in the defense and space programs. Over the next 30 years, industry needs began to shift as a result of a growing national competitiveness within the context of a more global economy (Lucena, et al., 2008). In 1985 the National Research Council sounded the call for engineers to heighten their professional skills, including communication, teamwork, and developing an understanding of economic and societal impacts on the engineering profession (National Research Council, 1985). By the mid 1990's industry and government officials recognized a disconnect between the skills that engineering graduates were learning through formal engineering education and those needed to compete in the engineering workforce (Lang, Cruse, McVey & McMasters, 1999; Duderstadt, 2008).

In 1994, the Accreditation Board for Engineering and Technology (ABET), with financial support from the National Science Foundation, held a workshop consisting of representatives from industry, government, and academia. At the workshop, representatives discussed the disconnect between education and practice, acknowledging that the accreditation criteria used to evaluate engineering schools were too rigid and prescriptive to meet the rapidly changing technical environment that engineering graduates would be entering (Lang, Cruse, McVey, McMasters, 1999). As a result of these discussions, ABET revised the accreditation criteria to reflect a learning outcomes-based approach that was more holistic and consisted of eleven outcomes known collectively as the ABET (a-k) outcomes (ABET, 2012). The ABET (a-k) learning outcomes represent both technical and non-technical competencies that engineering students need to demonstrate including:

(a) Ability to apply knowledge of mathematics, science, and engineering

(b) Ability to design and conduct experiments, as well as to analyze and interpret data

(c) Ability to design a system, component, or process to meet desired needs

(d) Ability to function on multi-disciplinary teams

(e) Ability to identify, formulate, and solve engineering problems

(f) An understanding of professional and ethical responsibility

(g) Ability to communicate effectively

(h) Broad education necessary to understand the impact of engineering solutions in a global/societal context

(i) Recognition of the need for, and an ability to engage in life-long learning

(j) Knowledge of contemporary issues

(k) Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (ABET, 2012).

The criteria, known as Engineering Criteria 2000 (EC2000), represented a radical change in the approach to engineering education, and remain in place at all U.S. accredited engineering programs. The criteria also serve as a guideline for engineering programs worldwide (Hirleman, Groll, & Atkinson, 2007; Magee, 2004).

While the EC2000 shifted the emphasis from curricula inputs to student learning outcomes, each institution is responsible for determining how the outcomes are achieved and assessed (Lang, et al., 1999). The criteria are intentionally flexible in order to allow individual institutions to utilize their unique capacities in designing the overall educational experiences necessary to achieve these eleven outcomes.

In 2007, Passow conducted a meta-analysis of ten different studies representing almost 6,000 engineers to determine what the relative emphasis on the various learning outcomes should be. She used the ABET (a-k) outcomes as the common construct for the study, mapping the various competencies from each of the ten studies onto the ABET outcomes, and listing separately those competencies that were not considered comparable. Since Passow (2007) was interested in determining the relative emphasis among the competencies rather than the absolute importance ratings (using a Likert scale), she chose to compare the mean value of specific competencies to the overall mean value of the ABET (a-k) outcomes in a given study. This method resulted in the rank ordering of the importance of each of the competencies including (in order): problem-solving, communication, ethics, life-long learning, experiments, teams, use of engineering tools, and design as the most important competencies; knowledge of math, science and engineering as being of average importance; knowledge of contemporary issues and impact as being of least importance (Passow, 2007, p. 1). In addition, she identified two additional competencies that were not part of the ABET (a-k) outcomes that ranked between the top two levels of importance: decision-making and commitment to achieving goals (Passow, 2007, p. 13).

The results of this meta-analysis indicate that competencies that include abilities, attitude and skills are considered to be more important than strictly technical knowledge. This is not to say that technical knowledge is not important. In fact, the study demonstrated that practitioners believe knowledge of math, science, and engineering to be important, but ranked each lower in importance compared to the more professional skills of problem solving, communication, ethics, and teamwork.

In 2015, the ABET Engineering Accreditation Commission (EAC) proposed changes to Criterion 3 as a result of perceived shortcomings in both application and interpretation of the a-k learning outcomes. The proposed changes reduced the learning outcomes from eleven to seven outcomes that include 1) engineering problem solving, 2) engineering design, 3) measurement, testing and quality assurance, 4) communication skills, 5) professional responsibility, 6) professional growth, and 7) teamwork and project management skills (ABET, 2015). The EAC task force concluded that, "some of the (a)-(k) components were interdependent, broad and vague in scope, or impossible to measure. As a consequence, program evaluators were inconsistent in their interpretation of how well programs were complying with Criterion 3" (ABET, 2015, website, para. 6). Critics of the proposed changes argue that the new outcomes will "lower the bar" in engineering education by diminishing the importance of educational breadth, especially related to having an understanding of contemporary issues, professional ethics, and working in a multidisciplinary environment (Riley, 2016). The EAC task force is currently soliciting feedback from stakeholders on the proposed learning outcome changes.

d. Math

The Mathematical Association of America (MAA) provides curriculum guidelines to higher education math programs through a Curriculum Guide that is revised approximately every ten years. The Committee on Undergraduate Program in Mathematics (CUPM) of the MAA collects information from mathematicians and colleagues from partner disciplines as input into the guide. In a discussion paper published by the committee, the authors note that, "With far greater diversity among institutions, preparation of students, and expectations of higher education, it is no longer either possible or desirable to simply list and describe the content of a few courses that would constitute a major. We must ask ourselves, 'What should students know?' (CUPM, 2010, p.2). The MAA recognizes that mathematics pervades essentially all of the majors within the STEM fields (and beyond), not only those students majoring specifically in mathematics. Learning outcomes, therefore, must be broad enough to incorporate all of the math- related disciplines, including “pure and applied mathematics, mathematics education, computational mathematics, operations research and statistics” (MAA, 2004, p. 3). The guidelines include:

- Achieving mastery of diverse mathematical concepts and the connection between broad themes such as linearization, optimization, and symmetry
- The ability to think critically and analytically about problems and then to both solve and interpret the solutions
- The ability to achieve and understand mathematical proofs
- The ability to apply mathematical knowledge to other disciplines or other areas of mathematics
- The ability to understand mathematics within the contemporary context
- The ability to use a variety of technology tools such as statistical software, programming languages, and math-related software
- The ability to communicate mathematics both orally and in writing

(MAA, 2004, p. 5-7)

e. Summary of STEM Learning Outcomes

There are obvious similarities in the described learning outcomes in the STEM fields. All of the fields expect students to learn technical, discipline-specific concepts and have the ability to integrate theory with practice using critical thinking and analytical skills. Additionally, students in the STEM disciplines should be able to solve complex problems, work within a team environment and to communicate ideas effectively, both orally and in writing. Most disciplines also articulate a need to develop a sense of professional responsibility including ethics and life-long learning. These major themes will help guide the interviews conducted during this research.

3. Assessment of Learning Outcomes

While most colleges and universities are individually adopting a set of learning outcomes for their students, measuring those outcomes creates a different set of challenges. In his much-cited book on student learning outcomes, Harvard University President Emeritus, Derek Bok declared "professors seldom receive clear evidence of how much students are learning…Course evaluations offer some insight, but they usually focus on whether the instructor was clear, knowledgeable, and accessible to students while saying little about how much students think they learned" (Bok, 2006, p. 315). Similarly, Kuh and Ikenberry (2009) label current success measures such as course credits, certificates and even degrees as "surrogate markers" of student accomplishment (p. 5). In a brief published by the Institute for Higher Education Policy, Clifford Adelman claims that

> the 'voluntary system of accountability' adopted by a large segment of higher education—which tells the public how many pieces of paper colleges and universities handed out (to whom and when), how much students liked different aspect of their experience at an institution, and how much scores on tests of something called 'critical thinking' improved for a sample of students between entrance and senior year—is more show than substance (Adelman, 2008, p. 1).

The National Survey on Student Engagement (NSSE) reports annually on the learning development of students from over 600 colleges and universities. The survey focus, however, is on student behavior—how students spend their time—rather than on what they have learned. Traditional methods of assessing learning outcomes such as examinations may be effective at measuring subject knowledge, however, they are not ideal at measuring other important outcomes such as teamwork, communication, and critical thinking skills (Major & Palmer, 2001).

While assessment is obviously a challenging task, one method of evaluating how well colleges and universities are achieving their goals of meeting identified student learning outcomes is to ask employers to evaluate entry level employees on their skills and competencies. In 2010 the Association of American Colleges and Universities (AAC & U) commissioned a study of employers' perceptions of the learning outcomes that colleges and universities should be stressing. The report was based on a survey of approximately 300 employers, and resulted in a list of the top ten areas in which employers believed that college students need improvement, including:

1. The ability to effectively communicate orally and in writing (89%)
2. Critical thinking and analytical reasoning skills (81%)
3. The ability to apply knowledge and skills to real-world settings through internships or other hands-on experiences (79%)
4. The ability to analyze and solve complex problems (75%)
5. The ability to connect choices and actions to ethical decisions (71%)
6. Teamwork skills and the ability to collaborate with others in diverse group settings (71%)
7. The ability to innovate and be creative (70%)
8. Concepts and new developments in science and technology (70%)
9. The ability to locate, organize and evaluate information from multiple sources (68%)
10. The ability to understand the global context of situations and decisions (67%) (Hart Research Associates, 2010. p. 9).

This study suggests that, at least from the employer viewpoint, students may not be graduating with the necessary knowledge, skills and behaviors needed in the modern workforce.

Relevant to the current study, understanding the employer viewpoint helps to shed light on why employers place such high value on industrial internships, and what may be missing within the academic experience.

a. Industry Assessment of STEM Learning Outcomes

Because most STEM programs are accredited, they must demonstrate how well students are learning specified goals or stated learning outcomes as part of the accreditation process. In fact, in their study of student learning outcomes, Kuh & Ikenberry (2009) noted that, "Accreditation is …the major driver of learning outcomes assessment [in American higher education]" (p. 26). Assessments vary in form including: faculty perceptions of student learning, measured by grades on exams or homework, perceptions of performance applying principles through laboratory experience, portfolios or capstone projects, students' self-perceptions as to how well they met stated learning outcomes, or input from external constituents such as alumni or employers.

Several studies have sought to gather feedback from STEM employers as a way of identifying and assessing the learning outcomes necessary for practice. Many of these studies focus on individual industries such as defense/aerospace (McMasters, White, Williams, & Okiishi, 1999), construction (Ahn, Pearce, Kwon & Shin, 2012), manufacturing (Lahidji & Albayyari, 2000), industrial technology (Meier, Williams, Humphreys, & Centko, 1999), and agriculture (Brumm, Mickelson, Steward, & Kaleita, 2006). While the specific technical skills needed for individual industries varied (e.g. skills in use of CAD tools, ability to design a subsystem), the results of these surveys suggest similar gaps in professional skills. Most researchers agree that entry level engineers and scientists are proficient in technical knowledge but lack interpersonal communication skills, the ability to work in cross-functional teams, and a conceptual understanding of the “big picture” of the larger business environment (Meier, et al., 1999; Reich, 1993; Sageev & Romanowski, 2001).

A 2004 survey of practicing engineers’ assessment of student’s preparation for entering the workforce suggested that new engineers were either adequately or well prepared in their technical and problem-solving skills. However, approximately 75 percent of employers believed that students were not well prepared in terms of communication and teamwork skills. Likewise, over 90 percent of respondents believed that students were not well prepared in understanding the organizational, cultural, and environmental context of their work. Only around 50 percent believed that students were even adequately prepared in these areas (See Table 1).

Table 1: Employer Ratings of Recent Graduates

How well prepared are recent engineering graduates	**% Inadequately prepared**	**% Adequately prepared**	**% Well prepared**
To use engineering, math, science, and technical skills	08	44	48
To apply problem-solving skills	19	55	26
To communicate and work in teams	24	54	22
To understand the organizational, cultural, and environmental contexts and constraints of engineering practice, design, and research	47	46	07

(Lattuca, Strauss & Volkwein, 2006, p. 9).

This study was done in collaboration with six professional societies (AIAA, AICHE, ASCE, ASME, IEEE, and IIE) and resulted in over 2,000 industrial responses across 20 industry sectors.

b. Academy Response to Learning Gaps

As the deficits in STEM student learning outcomes came to light, scientific organizations including the National Academies of Science (NAS) and the National Science Foundation (NSF) began to fund studies into more effective teaching practices in STEM education. Many of the resulting studies focused on pedagogical approaches that use a “learner-centered” paradigm rather than a “teacher-centered” paradigm (Barr & Tagg, 1995), and include inquiry-based, collaborative approaches that engage students in the learning process (Boyer, 1990). Pedagogical approaches that promote active, collaborative learning have been well-documented to improve student learning (Kuh, Kinzie, Schuh, & Witt, 2005; Pascarella & Terenzini, 2005). In a review of papers presented at the National Academies of Science workshop, Fairweather (2008) noted that most recent pedagogical reforms in the STEM fields are geared toward active, collaborative approaches such as problem-based learning.

4. Learning Outcomes in Problem-based Learning

In 1993 Albanese and Mitchell published a thorough literature review of the outcomes of problem-based learning over a span of twenty years in the medical community. The literature revealed that students who participate in problem-based learning were more likely to enter the medical profession, generally enjoyed their programs more than those in traditional classes and sometimes, though not always, had improved scores on clinical exams. Major and Palmer (2001) expanded the review of the literature to include programs beyond the medical community to professional schools, noting that students who participated in problem-based learning environments showed improved problem-solving and critical thinking skills as well as communication skills compared with those in traditional instruction. Students also had better attitudes toward learning and were able to apply theory to practice. However, the study also showed that students in problem-based learning environments showed either no difference or a decrease in knowledge of basic scientific principles (Major & Palmer, 2001). The authors hypothesized that these results could be due to the fact that problem-based learning focuses on “learning to learn” (p.6) rather than on mastery of specific concepts. Schmidt, Vermeulen & van der Molen (2006) reported similar results in their study of 820 medical students across 18 professional competencies. This study reported that students who participated in problem-based learning had improved interpersonal and problem-solving skills along with enhanced self-directed learning and the ability to gather information. However, the students showed no increase in academic competency and an actual decrease in subject knowledge (Schmidt et al., 2006).

Pointing, again, to studies that show lower test scores for students in problem-based learning environments and a general lack of empirical evidence for improved student learning outcomes in engineering education, Prince (2004) noted that there is “broad but uneven support” for active, collaborative problem-based learning within the STEM fields (p.223). He acknowledges the benefits of problem-based learning in students’ attitudes, work habits, teamwork and critical–thinking skills, but notes that the main problem with studies of problem-based learning is a lack of consensus on the common elements of problem-based learning practices.

Walker and Leary (2009) attempted to explain these inconsistencies in problem-based learning outcomes through a meta-analysis of 82 different studies across 201 outcomes. The study considered moderating factors such as the form of implementation of problem-based learning, the types of problems used, the academic discipline and the assessment level. While results of the meta-analysis suggest that overall, problem-based learning students performed as well or better than those in lecture-based classes, moderating factors accounted for different levels of learning outcomes. For example, closed-loop methods seemed to improve student learning over more open-looped methods. In addition, learning outcomes appeared to vary by academic discipline, with teacher education and the social sciences showing improved learning outcomes over traditional pedagogies. Science and engineering, however, showed no significant difference in learning outcomes over traditional lecture-based methods (Walker and Leary, 2009).

In addition, the study revealed that differences in the type of problem contributed to differences in learning outcomes. In general, problems at either end of the spectrum—from logical problems at one end, to unsolvable dilemmas at the other end provide the least effective problems for learning. While problems that provide more opportunity for critical thinking, examination of evidence, and collaboration of multiple viewpoints provide the best problems for learning. These types of problems include case studies, decision-making problems, trouble-shooting problems, design problems and diagnosis/solution problems (Walker & Leary, 2009).

Finally, the study showed that assessment level was linked to student learning outcomes. Walker and Leary (2009) utilized Sugrue's (1995) framework to break down the assessment of student learning outcomes into individual components including the concept level, the principles level, and the application level. At the concept level, where students are learning and defining new concepts, traditional pedagogical approaches such as lecture and homework problems seem to provide the best learning environment (Walker and Leary, 2009; Prince, 2004). However, at the principle and application levels, problem-based learning approaches provide a better platform. At the principle level, students begin to construct relationships between concepts, and at the application level, they use those concepts and principles to solve problems. At both of these levels, problem-based learning provides students with the opportunity to apply their learning to a real-world problem, elucidating the concepts and principles in a more direct way.

Furthermore, in an effort to understand the mechanism by which students are learning, the study examined the process level outcomes of five different studies. The study indicated that students in a problem-based learning environment utilize more backward-driven, or hypothesis-driven reasoning than those in lecture-based classes. Introduced by Albanese and Mitchell (1993), thought processes can be understood as either forward-driven (data-driven) or backward-driven (hypothesis-driven). Forward-driven reasoning stems from having clear cognitive knowledge structures that can be called upon for rapid diagnosis of problems. Backward-driven reasoning consists of testing hypothesis through a series of probabilistic models and principles (Albanese and Mitchell, 1993). Experts tend to be better at forward-driven reasoning because they are able to draw from a well of experience and knowledge. Novices, however, do not have the knowledge-base to use this approach and commit fewer errors when using a backward-driven approach (Hmelo, Gotterer, & Bransford, 1997).

While problem-based learning is gaining popularity in the academic setting, it has not been widely adopted. Barriers to implementing problem-based learning include higher costs associated with the approach, difficulty with course sequencing, faculty workload, and lack of sufficient faculty rewards (Fairweather, 2008).

5. Learning Outcomes in Internships

While students may be benefiting from improved learning in problem-based learning environments, STEM employers consistently express a preference for hiring students who have participated in internships over students who have not (Dabipi, Dingwall, & Arumala, 2007; NACE, 2014). In fact, 74% of employers prefer to hire students who have had relevant work experience, and of those, 60% further prefer that the experience to be through an internship or co-op (NACE, 2014). Employers in the STEM fields believe that internships provide the platform for students to gain the skills, competencies, and dispositions they may be missing in the academic classroom

Employers recognize the value that internships provide both from a subject content and professional viewpoint, and many studies have examined the benefits gained from participation (Jackson, 2013; Westerberg, & Wickersham, 2011; Varghese, et al., 2012). Some of these benefits include: putting theory into practice (Martin & Wilkerson, 2006), interacting with other professionals within the profession (Rowe & Mulroy, 2004), improved self-confidence (O'Brien, Haughton & Flanagan, 2001), and gaining insights into specific discipline and business environment (Samuelson & Litzler, 2013). In a 2001 study of medical students, Australian researchers reported that students who participated in internships had improved self-confidence, decision-making skills and ability to prioritize tasks. They also reported an increased awareness of the importance of teamwork and leadership skills and a reduction in anxiety when faced with future real-world situations (O'Brien, et al., 2001).

A 2012 study of 150 STEM students who participated in a ten week internship at NASA's Langley Aerospace Research Summer Scholars (LARSS) program sought to determine how the internship "contributed to the development of 21st century workplace skills (Pinelli, & Hall, 2012, p. 3). Both interns and mentors were surveyed as to their perceptions of interns abilities around 12 workplace competencies that included technical skills (technical, computer, and computational skills), analytical skills (critical thinking/problem-solving, analytical thinking, and innovation), and professional skills (oral and written communication, judgment, collaboration, time management, and adaptability). Results of the study indicated that students benefited from the internship by gaining self-confidence, an improved understanding of the workplace, adaptability, and collaboration skills. However, the mentors expressed some concerns as to the oral and written communication skills, level of creativity, technical, analytical and decision-making skills, as well as students' ability to self-regulate their behavior. Interns expressed a lack of ability to apply knowledge learned in the classroom to the internship experience (Pinelli &

Hall, 2012). This study provides valuable information because it offers insights from both employers/mentors as well as the interns themselves. The mentors provide a direct evaluation of the students' knowledge, skills, and abilities vis-à-vis those needed for actual practice. The students provide a self-reflection as to the skills and competencies they believe they have or have not gained. Taken together, this information offers a clearer picture of what students are learning and what they may be missing within the workplace setting.

While internships provide an opportunity for students to gain hands-on experiences in their fields of study, they may also provide students the platform for gaining identified STEM learning outcomes. In 2005, researchers at the Fulton School of Engineering at Arizona State University conducted a study to assess the learning outcomes of the students in two of their internships programs, the Engineering Internship Program (EIP) and the Harrington Department of Bioengineering Internship Program (Haag, Guilbeau & Goble, 2006). The goal of the study was to assess the extent to which students who participated in internships achieved the ABET (a-k) learning outcomes. Researchers used a survey instrument that was sent to 52 industrial managers across six different engineering areas. Results of the survey indicated that interns demonstrated strengths in foundational math and engineering principles, design, teamwork, and an interest in continuous learning. However, they identified areas for improvement in awareness of societal issues and in some communication skills including writing formal reports and giving presentations (Haag, et al., 2006). In discussion of the relevance of the intern program, one employer commented, "Internships are a very critical part of today's educational process. As an employer I would be reluctant to hire a student fresh out of school without any work experience." (Haag, et al., 2006, p. 3).

While many studies have demonstrated the benefits of STEM internships, especially in terms of technical and professional development, they are limited by the variability in the nature and quality across individual positions or companies (Taylor, 1988; Jonassen, Strobel, & Lee, 2006; Samuelson & Litzler, 2013). Some of these inconsistencies include the type and level of tasks that the intern is asked to complete (Jonassen et al., 2006), how interns are treated by employers (Samuelson &Litzler, 2013), the type of training and mentoring they receive (Samuelson & Litzler, 2013; Fifolt & Searby, 2010), the assumptions about what the internship will be like (Fifolt & Searby, 2010), the level of preparation the student has coming into the internship (Fifolt & Searby, 2010), the amount of autonomy within the internship (Taylor, 1988), and the students' beliefs about their ability to make a genuine contribution to the organization (Litzler & Samuelson, 2013).

While there is some research on the benefits of internships on student persistence, there is surprisingly little research as to the mechanism by which students are learning through the internship experience. Samuelson and Litzler (2013) reported that mentorship during an internship was related to students' persistence in the engineering discipline, especially for female students. The mentorship provided support and opportunities for networking and the ability to develop professional connections. The study also showed that students who were able to build confidence in their skills and knowledge through the internship also persisted in engineering (Samuelson & Litzler, 2013).

Other studies have shown that internships provide students with insights into the engineering industry (Sheppard, Matusovich, Atman, Streveler, & Miller, 2011), and that socialization activities during internships can help students to develop professional skills and to work within their organizations' culture (Rowe & Mulroy, 2004; Parsons, Caylor & Simmons, 2005). These studies point to experiences that give students the opportunity to practice communication and collaboration skills within the corporate environment. However, more research is needed to understand the mechanism by which students are actually gaining the skills and competencies they need to be effective in the STEM workplace.

C. Literature Summary

Both educators and employers understand the need to graduate students with the knowledge, skills and behaviors needed to be successful in the rapidly-changing global economy. While many groups have undertaken the task of identifying those outcomes from both a broad educational perspective and through discipline-specific skills and competencies (Kuh and Ikenberry, 2009; Lang, Cruse, McVey, & McMasters, 1999, ABET 2014), there is still debate as to the learning outcomes students need. Within the STEM fields, professional societies and accreditation agencies have led the way to outlining a framework for STEM student learning outcomes. Across the STEM disciplines, students need a solid foundation in discipline-specific concepts combined with strong analytical and critical thinking skills and the ability to integrate theory with practice. In addition, they must develop the professional skills necessary to be effective in a world-economy that includes strong communication and teamwork skills and a sense of professional responsibility.

However, measuring those outcomes presents a real challenge to educators. Relevant to the current study, industrial perceptions offer the best starting place, if we are to consider the reason why employers are not able to hire enough STEM graduates with the correct skills and competencies needed for practice. In addition, understanding the employer viewpoint helps to shed light on why employers place such high value on industrial internships, and what may be missing within the academic experience.

As more active and collaborative pedagogies such as problem-based learning developed, educators in the STEM disciplines have been moving toward these “learner-centered” approaches. However, while the research on problem-based learning shows significant improvements in students' problem-solving, critical thinking, and teamwork skills as well as individual attitudes and work habits, studies indicate little or no improvement in concept-level learning. Understanding the mechanism by which students learn in a problem-based learning environment would shed light on how educators can more effectively structure the learning experience.

Finally, a closer look at STEM internships reveals that internships provide benefits from both a subject content and a professional viewpoint. This helps to explain why STEM employers consistently express a preference for hiring students who have participated in internships over students who have not (Dabipi, Dingwall, & Arumala, 2007; NACE, 2014).

The current study will expand our understanding of the mechanism by which STEM students are acquiring the skills and competencies they need by focusing on the detailed experiences of young STEM professionals who, as students, participated in different types of experiential learning environments.

CHAPTER 3

METHODS

A. Introduction

Conceptually, this research is informed by the integration of three components: the theories that describe experiential learning and the social/cognitive structures underlying learning experiences, what we know through the literature about the learning outcomes associated with problem-based learning and internships, and my personal experiences with students who have participated in both internship and problem-based learning in my role as the Director of the Engineering Career Center at a large research university.

The theoretical framework suggests that experiential learning provides students with the opportunity to assume a more active role in the learning process by engaging in concrete experiences, forming abstract concepts relative to the experience, and applying what they have learned in future experiences (Kolb & Fry, 1975). This hands-on approach helps students to gain the confidence and self-directed learning skills that result in improved problem-solving, information gathering, and interpersonal skills (Little, 1993; Harrisberger, 1976; Cantor, 1997; Schmidt, et al., 2006). Further, both social and cognitive processing described by Lent, Brown and Hackett's Social Cognitive Career Theory (1994) adds to our understanding of how social constructs enhance the learning experience by observing others' behavior, introducing new perspectives on a problem, and by necessitating communication and teamwork skills. While personal characteristics and background experiences contribute to an individual's learning, SCCT suggests that the environment and contextual influences also affect the learning outcomes through the development of an individual's sense of self-efficacy and outcomes expectations (Lent, et al., 2002).

Literature on problem-based learning and internships adds to our understanding of the effects that environment and contextual influences have on student learning. We know that students who participate in either problem-based learning environments or internships have improved problem-solving, critical thinking, and communication skills and are better able to apply theory to practice over those in lecture-based classes (Major and Palmer, 2001; Jackson, 2013). Some of the factors that seem to affect these outcomes include level of mentorship (Samuelson & Litzler, 2013; Fifolt & Searby, 2010), type of problem or project the student engages in (Jonassen et al., 2006), and type of implementation of experience (Walker & Leary, 2009). However, learning outcomes vary between these two types of experiences, especially in regards to content knowledge (Schmidt et al., 2006; Prince, 2004; Major & Palmer, 2001). The extent to which these factors play a role in the learning outcomes of STEM students has been minimally documented. Other undiscovered factors may play a role in the achievement of learning outcomes in experiential learning environments.

Throughout my 10 years of experience in Engineering Career Development at the University of Massachusetts, I have had the opportunity to hear hundreds of students' perspectives on learning technical and professional skills in lecture-based and problem-based classes, as well as unstructured problem-based learning environments and industrial internships. There are a myriad of factors that seem to affect the learning process for these students, some that are pivotal in affecting their ability to gain employment in the STEM fields upon graduation and success in their future careers. Understanding more about these factors: what they are and the mechanism by which they are achieved, would enhance our ability to develop programs that provide environmental and contextual influences that lead to improved student learning, both within and outside of the academic classroom.

B. Purpose and Research Questions

The purpose of this study is to explore the ways in which early career STEM professionals gain the skills and competencies needed for STEM practice. Specifically, the study examined the perspectives of early career STEM professionals who, as students, participated in either problem based learning initiatives or internships, in order to understand the qualitatively different ways in which these professionals gained the skills they need to be successful engineers and scientists. The study employed a qualitative approach as a way to gain a rich understanding of the phenomena from the perspective of those who are actually experiencing it (Rossman & Rallis, 2003). Specific to the current research, a qualitative approach allowed for a more in-depth understanding of the former students' experiences within the context of professional STEM practice.

Early career STEM professionals who participated in problem-based learning or internships as students offered unique insights into the mechanism by which they learned the necessary STEM outcomes because of their "lived experiences and worldviews" (Rossman & Rallis, 2003, p. 190) in both experiential learning and in STEM practice. The study drew from an interpretative framework, acknowledging that an individual's experiences are mediated by their perceptions of those experiences.

The research was guided by three questions:

1. What are the qualitatively different ways that early career STEM professionals experience the central STEM learning outcomes in the workplace?
2. How did these early career STEM professionals, who as students, participated in problem-based learning and those who participated in internships, gain these competencies?

3. What do these early career STEM professionals perceive to be the critical factors that contributed to their ability to develop the competencies necessary for STEM practice?

C. Description of problem-based learning programs: M5 and iCons

Marcus 5 (M5) is an academic makerspace situated within the Electrical and Computer Engineering (ECE) building at the University of Massachusetts. In general, a makerspace is a place where community members can come together to create, learn, and innovate. Also known as project space or a tech sandbox, a makerspace provides a variety of tools and equipment that enable members to design and develop new ideas. Makerspaces vary in scope and size depending upon the needs of the community they serve. M5 is an educational initiative of the University of Massachusetts ECE Department, and holds as its mission "to enable members of the UMass community (undergraduate students, graduate students, faculty and staff) to advance their technical interests through experimentation, exploration, collaboration, entrepreneurship and documentation" (B. Soules, personal communication, 2014). To this end, staff, equipment, facilities and supplies are available at no charge to help community members design, test, prototype, construct and document their projects. Each semester the department offers a one-credit pass/fail course that M5 students can enroll in if they want academic credit for their project work. While there is a heavy emphasis on self-directed learning, the space is facilitated by two ECE faculty members.

The Integrated Concentration in Science (iCons) program at the University of Massachusetts is a 20 credit-hour multidisciplinary science and engineering educational program with concentrations in biomedicine and renewable energy for STEM students. The mission of the program is "To produce the next generation of leaders in science and technology with the attitudes, knowledge, and skills needed to solve the inherently multi-faceted problems facing our world" (UMass, 2014). The program was designed to enhance existing science and engineering programs through an integrated curriculum that uses real-world societal problems as the foundation for learning. For example, 2014 iCons graduates explored the cholera epidemic in Haiti and the development of algae-based biofuels.

iCons program creators recognized the need for students to develop a depth of concept knowledge in the foundational sciences and math that could then be used for problem-solving. Therefore the program is structured over four years with students fulfilling pre-requisite courses such as calculus, biochemistry, or molecular biology in the fall semesters of their second and third year and participating in vertically-integrated iCons classes in the spring semesters. The required iCons classes are broken into two different tracks: biomedicine and renewable energy. The senior year consists of a year-long interdisciplinary research project. The overall program includes case-study analysis, laboratory work, and research, and is team-based, not only for the student participants, but also for the faculty facilitators. The goal of the program is to enable students to use real-world problems as the platform for developing technical, communication, teamwork, leadership, and research skills that are relevant for solving society's most pressing problems.

The program began in 2010 and, at the time of this research, had graduated two cohorts of 29 and 28 students, respectively. Students that graduated from the iCons program came from a range of STEM majors including Biology, Biochemistry, Microbiology, Environmental Science, Molecular Biology, Chemistry, Physics, Mathematics, BDIC: Science, Technology and Society and Intellectual Property, Chemical Engineering, Public Health, Food Science, Neurobiology, Electrical Engineering, and Geology.

D. Method

Because I am interested in understanding the different ways that early career STEM professionals gain the skills and competencies necessary for STEM practice, this study employed a research method that explored the variations on how STEM professionals learned to approach and carry out their work. Phenomenography is a research method developed to qualitatively examine the "different ways in which people experience, conceptualize, realize and understand various aspects of phenomena in the world around them" (Marton, 1986, p.31). Entwistle (1997) argued that rigorous data collection and analysis are the hallmarks of phenomenography's distinct approach to research.

Phenomenography was first used by Marton and Säljö (1976) to explore the differences in the process of learning and the learning outcomes of students in Sweden. In this study, Marton and Säljö interviewed students and examined the qualitatively different ways they approached and comprehended an article on curriculum reform. The aim of the study was not only to describe the different conceptions of the students, but also to understand how different processing levels lead to different learning outcomes. The study resulted in a hierarchy of categories of learning from surface level to deep level that were then associated with desired learning outcomes.

Since its development, other researchers have used the phenomenographic approach to understand the qualitatively different ways of experiencing certain phenomena within the STEM fields. For example, understanding the mole concept in chemistry (Lybeck, Marton, Stromdahl & Tullberg, 1988), understanding sound concepts in physics (Linder & Erickson 1989), conceptions of learning math (Crawford, Gordon, Nicholas & Prosser, 1994), conceptions of learning civil engineering (Franz, Ferreira & Thambiratam, 1997), and sustainability engineers' conceptions about their profession (Mann, Dall'Alba & Radcliffe, 2007). Booth (1993, 2001), explored the variations in how computer science students learned programming in two different venues: an introductory course, and later in a project-based learning course.

Relevant to the current study, Sandberg (2000) and Daly, Adams and Bodner (2012), used a phenomenographic method to examine the variations in practicing engineers' perceptions within the professional environment. Sandberg (2000) interviewed 20 engineers at Volvo to understand the different perceptions that the engineers had in regards to engine optimization. Daly, et al. (2012) examined the qualitatively different ways that engineers and scientist understand and experience design.

> The goal of the study… was to understand design professionals' meanings and critical aspects associated with their design experiences by probing the following guiding research question: What are the qualitatively different ways practicing designers from a variety of disciplines experience design?" (p. 189). Their aim was to move beyond simply asking *what* designers do to "how designers view, approach, and proceed through design work as well as the result of designers' synthesis of their knowledge, skills and experiences (p. 209).

In the current study, it is important to understand not only what skills and competencies practicing STEM professionals use, but also how they perceive the learning of these skills occurred. For example, a STEM professional may have developed teamwork skills as a student through participation in a class project, as part of a research group, through an internship, or in working with peers in extracurricular environment. Or, they may not have developed the skill until working in the professional environment. Exploring the variations of how early career STEM professionals gain the knowledge, skills and behaviors needed for STEM practice, will create a "landscape view that encompasses diverse perspectives that distinguish critical features" of the STEM learning phenomena (Daly, et al., 2012, p. 193).

E. Sampling and Recruitment

One of the unique features of a phenomenographic study is the focus on investigating the different ways in which a specific phenomenon is experienced (Entwistle, 1997; Marton, 2000; Richardson, 1999). This focus necessitates a sampling strategy that takes into consideration individuals who have experienced the phenomena in a variety of ways. For example, if a researcher were studying the learning outcomes from a specific class, the sample would not only include the top performing students in the class, or only male students. Rather, the sample would include individuals that represent a range of ways in which the phenomena was experienced. Moreover, according to Creswell (2009), in qualitative research the researcher should select individuals who will "best help the researcher understand the problem and the research questions" (p. 178).

I sampled participants who were working in STEM jobs, because they would have an in-depth personal knowledge of the key skills and competencies that they have needed to be successful in their careers thus far. Likewise, because they participated in experiential learning programs as students, they were aware of the effects that those programs had on their own learning experiences. A total of 18 participants were purposefully selected based on the following factors: graduated with a STEM degree, participated in some type of experiential learning while they were a student, and currently working as a STEM professional. While attempts were made to recruit only those early career STEM professionals who had been working for five years or less, I was unable to identify enough participants from the "science" sector. Therefore, I reached out to faculty asking for help identifying participants and received two offers to participate from mid-career STEM professionals. These participants had been working in the STEM field for thirteen years and majored in biochemistry and molecular biology and biology, respectively. Approximately three participants were selected from each of the following four groups: majored in a science discipline, majored in computer science (technology), majored in engineering and majored in math. Three participants were specifically sampled from those who participated in the iCons program, and three were sampled from those who participated in the M5 makerspace. In addition to reaching out to former engineering and chemistry students directly, I asked the coordinators of the M5 and iCons programs, the department heads of biochemistry and molecular biology and math, and the administrative director of Computer Science for assistance in identifying potential candidates for the study. An email describing the research was sent to all the identified potential participants asking for participation (Appendix I).

F. Interview Protocol

The interview protocol for the study was developed by creating a metric of common learning outcomes across the various STEM sectors as outlined by the professional societies and accreditation agencies (Appendix II). During the interview, participants were asked to describe how they experienced each of the learning outcomes within the context of their professional position, how they believed they learned the specific skills and competencies, and what they perceived to be the critical factor or factors in learning those skills and competencies. In addition, participants were asked if there were any skills or competencies that they use in their professional positions that they did not learn in school, and how hiring managers or recruiters evaluated these skills and competencies in the hiring process (Appendix III). While the interviews followed this protocol, they were open-ended, allowing participants to elaborate on the most salient issues. Participants were also asked to complete a demographic survey prior to the interview (Appendix IV).

G. Data Collection

Before collecting data, I received the necessary approval from the University of Massachusetts Institutional Review Board (IRB) to conduct the study and emailed participants in advance, summarizing the purpose and objective of the study and asking for their participation. I clearly stated that participation is voluntary, and reviewed the IRB consent form (Appendix V) with each of the participants before the actual interviews. Seventeen of the eighteen participants signed the participant consent form. Because one participant was living in Wisconsin and did not have access to a fax machine, he verbally consented to the interview which is recorded on his interview tape.

There were two components of data collection: a demographic survey and in-depth interviews. Before the interviews, participants received an email survey asking for demographic and background information (Appendix IV). Obtaining this information is important because, based on SCCT, "person inputs" such as race, gender, and disability status along with "background contextual affordances" such as birth order, family size and home environment influence a person's experiences and affect their sense of self-efficacy as well as their outcome expectations (Lent, et al., 1994; Allison & Cossette, 2007).

After that, I conducted semi-structured interviews throughout 2015. Interviews were conducted mainly in-person, though three interviews were conducted via phone, email and skype due to time and distance constraints. Interviews ranged from 41 minutes to 1 hour and 45 minutes, with the average interview time being 1 hour and 13 minutes. The interview protocol included asking participants the three research questions in relation to the common set of learning outcomes set forth by professional societies and accreditation agencies across the STEM fields. Questions were open-ended to allow participants to express what they believe to be the most salient issues and experiences in regards to achieving desired outcomes. Two additional interview questions addressed any perceived knowledge, skills, or competencies that may be missing in the stated learning outcomes, as well as participants' perceptions of how recruiters and hiring managers evaluated the learning outcomes (Appendix III).

H. Data Analysis

Interviews were transcribed word-for-word and analyzed using a multi-step, iterative process that included both an individual and collective perspective. The first step of the analysis included a careful reading of the individual transcripts aimed at familiarizing myself with the empirical content. The second step consisted of coding individual transcripts for keywords and concepts in order to identify the significant elements. According to Sjostrom & Dahlgren (2002), certain gauges can be used for assessing the importance of an element in a response including frequency of the statement, word, or concept; position of the word or concept in the response; and explicit emphasis placed on the word or concept. In addition, I took into consideration the theoretical framework of the research. For example, words or phrases such as "problem-solving", "teamwork", and "feedback" were coded as well as concepts concerning participants' backgrounds, or sense of self-efficacy.

Next, codes were condensed into central categories and entered into an Excel spreadsheet along with demographic and background information for each participant. The fourth step of the analysis included identifying the essential components of each category such as the need for conflict resolution in teamwork, or the impact of feedback from peers or supervisors. Linder and Marshall (2002) note that "new phenomenography" has shifted from simply describing a phenomena to "asking what critical aspects of the phenomenon are discerned by a learner" (p. 272).

Next, I did a preliminary comparison of the responses within the categories, looking for similarities and differences within the themes. This step is known as "horizontal division" because the researcher is looking across all transcripts rather than within individual transcripts (Kinnunen and Simon, 2012).

Finally, I created pivot tables to look at the relationship across themes in order to understand the range in which the concepts were being experienced by participants. For example, some participants experienced professional ethics as a "life or death" imperative that constantly informed their job, while others viewed professional ethics as a matter of simply doing the job they were paid to do. This range of comprehension, known as "outcome space" aided in the understanding of the possible ways that the phenomena was being understood and experienced.

I. Participants

Participants in the study were STEM professionals who, as students, participated in a variety of experiential learning programs including internships, research, and problem-based learning. Those who participated in problem-based learning came from two specific programs: Integrated Concentration in Science (iCons), a highly structured problem-based learning program, and M5, a loosely structured makerspace environment.

The participants graduated with degrees across the range of STEM majors: Science and Technology (Biology, Biochemistry and Molecular Biology, Computer Science), Engineering (Civil, Chemical, Computer Systems, Electrical and Mechanical), and Math. Seventeen of the participants graduated from the same large public research university, while one participant graduated from a different large public research university. Sixteen of the participants graduated with STEM degrees between 2010 and 2015, two participants graduated with a STEM degree in 2002. Eleven of the participants identified as White, four as Asian, one as Hispanic and two preferred not to answer. Thirteen of the participants were male and five were female. Sixteen of the participants had participated in an internship during their academic career, three had participated in the iCons program, three had participated in the makerspace, M5, and four had participated in research. In their professional capacity, the participants worked for a wide range of STEM-related industries including biotech, aerospace, commercial products, software, defense, insurance, energy, public works and government. Within these industries, participants worked in variety of functional areas including design, manufacturing, research, development, data analytics and project management. Participants' employers ranged in size and scope from an international Fortune 100 corporation to a major government organization focusing on national security to a five-person start-up company. Participants in the study can be characterized as follows:

Table 2: Participant Characteristics

Name*	**Gender**	**Race**	**Major in College**	**Industry (Current & former)**	**Functional Area**	**Internship**	**Problem-based learning**
Megan	Female	White	Math Economics	Large Gov't Agency	Survey Research	2	None
Mike	Male	White	Computer Engineering	Software/ E-commerce	Software Design & Development	1	M5
Daniel	Male	Prefer not to answer	Chemical Engineering	Consumer Products	Research & Development	None	iCons Research
Chris	Male	White	Biochemistry & Molecular Biology	Biotech	Project Management	1	None
Marco	Male	Hispanic	Mechanical Engineering	Consumer Products	Manufacturing	1	None
Ian	Male	Asian	Chemical Engineering	Aerospace	Manufacturing	1	None
Paul	Male	White	Electrical Engineering	Consumer Products	Research & Development	1	M5
Greg	Male	White	Computer Science	Consumer Products	Software Design & Development	1	None

Travis	Male	White	Aerospace Engineering	Large Gov't Agency Aerospace	Cost Analysis and Cybersecurity Manufacturing	2	None
Dave	Male	White	Biology	Biotech	Project Management	1	None
Tim	Male	White	Civil Engineering	Public Works	Water Design	2	None
Caroline	Female	White	Biochemistry & Molecular Biology	Start-up biotech	Research & Development	1	None
Kevin	Male	White	Computer Science	Consumer Products	Software Design & Development	1	None
Caitlin	Female	Asian	Math Electrical Engineering	Energy	Data Analytics	1	M5
Brian	Male	White	Chemical Engineering	Biotech Institute	Research	1	iCons
Andrew	Male	Prefer not to answer	Biochemistry & Molecular Biology	Biotech	Research	None	iCons
Nancy	Female	Asian	Computer Science	Consumer Products	Software Design & Development	1	None
Ashley	Female	Asian	Math	Insurance	Actuarial Project Mgmt.	1	None

*Names are pseudonymous

J. Limitations of the Study

The study was limited by the small sample size of participants as well as the fact that with the exception of one, all the participants graduated from the same public research institution. While I selectively sampled across science, engineering, technology, and mathematics, the sample pool did not include participants from every major within those larger categories. For example, there was no physics major in the sample pool. A larger, more in-depth study could include a broader range of participants from multiple educational backgrounds including smaller institutions, private institutions, or strictly technical institutions. In addition, because participants volunteered to participant in the study after receiving an email request from me or one of the faculty, the study may have attracted only motivated participants who were eager to share their stories.

A second limitation of the study was that results were based on self-reported perceptions of STEM professionals' learning experiences. Because the participants were asked to reflect back on their academic, internship or problem-based learning experiences, they may have inaccurately recalled information. According to Schacter (1999), the inability to accurately recall information can come from three broad categories: forgetting, distortion of information, or intrusive recollections of certain events. In this study, participants were reflecting back on events from between 1 and 5 years in the past, and for 2 participants, 13 years in the past. Therefore, some information may not have been recalled accurately or completely. In addition, four of the participants had worked at multiple jobs, and may not have recalled specific information accurately as a result of merging information.

A third limitation of the study is the bias that occurs with self-reported data. Social desirability bias occurs when participants are interested in how they, or the subject of the research, are being perceived by the interviewer (Archambault, 2011). While I took great care to explain the purpose of the study, participants may have had the desire to describe their college experiences, or a specific program where they were a member, in a positive light. Participants who were part of the iCons program, for example, may have been motivated to give a positive account of the program if they felt that the research were somehow part of a program evaluation. In order to limit this bias, I carefully explained the purpose of the study—not as a program evaluation, but as a way of understanding more about STEM learning outcomes and how they are achieved.

Finally, in any qualitative study, the researcher is part of the process (Seidman, 2006; Maxwell, 2005). Data collection consists of in-depth interviews of participants in which the researcher acts as a human instrument: asking questions, listening, taking notes, and describing, interpreting, and analyzing data. Since some of the participants of this study were engineering majors at the University of Massachusetts, they may have developed a relationship with me during their time as students. While my role as Director of the Engineering Career Center has helped me develop a common language with participants that may certainly benefit the study, I was careful to put aside preconceived notions of student internship or problem-based learning experiences and concentrate solely on the descriptions of the participants' experiences. Nonetheless, because of the potential for bias, some researchers recommend conducting phenomenographic research in teams in order to mutually agree upon categories in the data analysis phase (Bowden, 2000; Entwistle, 1997). When the research is carried out by a single researcher, best practices include making explicit the researcher's relationship to the field and to the participants as well any theoretical assumptions (Merriam, 2002; Walsh, 2000). Rands and Gansemer-Topf (2016) note that one strategy for ensuring trustworthiness in phenomenographic research is to "present the contextual relationships between the categories with rich, thick descriptions extracted from the transcripts so that the reader can understand the context" (p. 14), which I have attempted to do in this study.

CHAPTER 4

RESULTS

"In science and technology, your ideas are useless if they are trapped in your own mind. It is imperative that you are able to communicate well to be able to get your idea off the ground"

Andrew

A. Introduction

U.S. engineers and scientists are working to solve the most challenging technical problems in health, energy, and the environment and to maintain our nation's competitive and leadership position globally. In order to solve these complex problems, STEM professionals use a broad range of technical, problem-solving, analytical and communication skills. Using a phenomenographic approach, I interviewed 18 STEM professionals who had participated in a range of experiential learning experiences while they were students in order to explore the ways in which early career STEM professionals gain the competencies needed for STEM practice. I organized the data by the nine common learning outcomes identified by the STEM professional societies and accreditation agencies (Appendix I). These outcomes are:

a. Ability to apply mathematics, science, and/or engineering principles
b. Ability to identify, formulate and solve complex problems
c. Ability to communicate effectively (both orally and written)
d. Ability to function on multidisciplinary teams
e. Understanding professional and ethical responsibility
f. Ability to locate, organize, analyze and interpret information/data from multiple sources

g. Knowledge of contemporary issues and new developments in science and technology
h. Ability to use the techniques, skills, and modern technological tools necessary for solving complex problems
i. Recognition of the need for and an ability to engage in life-long learning

Because of strong inter-connectivity in responses, I grouped six of the learning outcome in pairs and presented them together in order to give a more complete and accurate representation of how the outcomes were experienced and learned by the participants. The pairs are: Learning outcome a-use of math, science and engineering principles is combined with learning outcome b-solving complex problems. Learning outcome c-communication skills is combined with learning outcome d-teamwork. Learning outcome g-having the knowledge of contemporary issues and new developments in science and technology is combined with learning outcome h-the ability to use the techniques, skills, and modern technological tools necessary for solving complex problems. The other three learning outcomes (e, g, and i) are reported individually.

For each of the learning outcomes, I wanted to understand 1) the way each participant experienced the learning outcome within the context of the workplace, 2) how the participant believed he/she learned the specific competency or skill, and 3) what the participant believed was the critical factor in learning the specific skill or competency. Recall that learning outcomes refer to the knowledge, skills and behaviors a student should learn after a course of study or educational experience. Competencies refer to the ability to apply knowledge, skills or behaviors to particular tasks or functions in the workplace. In other words, competencies are the integration of learning outcomes that are linked to workforce needs as defined by employers within the profession.

B. Participants' Responses

The participants' responses are summarized and presented below, organized by the nine learning outcomes. For each outcome, responses reflect the range of experiences described by participants. Phenomenography focuses on the variety of ways of experiencing phenomena—"ways of seeing them, knowing about them and having skills related to them. The aim is, however, not to find the singular essence, but the variation and the architecture of this variation by different aspects that define the phenomena" (Walker, 1998). Collectively, these variations constitute the outcome space of the phenomena.

Recall that six of the learning outcomes are presented together as pairs due to their strong connection with each other and in an effort to provide the most accurate description of the phenomena. The groupings are: use of math, science and engineering principles combined with solving complex problems; communication skills combined with teamwork; and having the knowledge of contemporary issues and new developments in science and technology combined with the ability to use the techniques, skills, and modern technological tools necessary for solving complex problems.

1. Learning Outcomes a, b: Use of math, science and engineering principles and solving complex problems; Ability to identify formulate and solve complex problems

Participants gave detailed descriptions of how they use basic and advanced math, science and engineering principles to carry out their day-to-day jobs. They consistently spoke of needing a strong foundation in physics, chemistry, materials science, biology and engineering in order to solve the challenging technical problems they face. The participants in this study felt confident in their ability to either apply these principles directly, or for their knowledge to serve as the foundation for more industry-specific use. Most participants expressed the need to combine foundational math and science knowledge with business knowledge in making products or processes more efficient and to stay competitive in the market. In addition, many of the participants noted that creativity in applying math, science, and engineering principles was critical to innovation and pushing beyond the limits of current technologies.

Participants in the study emphasized the ambiguous, open-ended nature of problems they face in industry. In most cases, these problems required both an analytical component and a synthesis of knowledge and skills as well as close collaboration with colleagues or clients. Participants expressed that they had not encountered the level of complexity in the problems they encountered in college. However, they felt confident, albeit challenged, to apply the knowledge, skills and competencies that they had when approaching more complex problems.

The use of math, science and engineering principles and the types of problems participants encountered varied *greatly* by industry type. Therefore, I have organized the results of these two learning outcomes by industry type/functional area.

There were five overarching industry types represented by the participants are biotech, computer software, commercial products, data analytics and public works. Within those industry types, participants' majors were as follows:

Industry Type/Functional Area	**Number of participants working in this industry**	**College major for participants working in this industry**
Biotech • Large drug company • Start-up biotech • Research Institutes	5	Biochemistry and Molecular Biology (3) Chemical Engineering Biology
Computer software • Major computer hardware/software • E-commerce	3	Computer Science (2) Computer Systems Engineering

Commercial products • Specialty Materials • Home-related products • Automotive • Aerospace	5 (includes 2 in manufacturing and 3 in research & development)	Chemical Engineering (2) Mechanical Engineering Electrical Engineering Computer Science Aerospace Engineering*
Data Analytics • Large Government Bureau • Insurance/Actuarial • Defense-related Government Agency • Non-profit Energy	4	Math (2) Aerospace Engineering* Double Major: Electrical Engineering & Math
Public Works • Water/Wastewater Consulting	1	Civil Engineering

*the participant who majored in Aerospace engineering worked 1 year at a commercial products company and 1 year at a defense-related government agency

Detailed descriptions of industry-specific tasks provide a helpful lens for understanding how participants use math, science and engineering principles in the workplace and the types of problems they encounter.

a. Biotech industry

For those in the biotech industry, the use of math, science and engineering principles included experimental design, hands-on laboratory work, using both basic math and statistical methods, forecasting, budget and cost analysis. Within the biotech industry, participants worked at a range of companies, both in regards to size and to type of work. These companies included a major, global biotechnology company, a small start-up biotechnology company, an educational research institution, and a biomedical and genomic research facility. Scientists and engineers working in the biotech field described their use of math, science and engineering principles as being a chief component of their job. Their tasks included doing calculations for concentrations and dilutions, setting up analytical equipment, cell-culturing and other experimental procedures, calculating drug needs for clinical trials, determining the probability of various gene mutations, using mark-up chain Monte Carlo for random sampling calculations, and using statistical methods to determine if a drug treatment was working. Caroline noted, "I started out in a hemostatis lab. I went on to have a position in a hem-onc (hematology/oncology) lab, so oncology mostly. I was looking for calcium transients…so I guess there was chemistry and a combination of physics and math." Chris, who had moved into more of a project management role explained, "I guess it's not scientific math, it's a little bit more of project planning in terms of study design, experimental design and trying to forecast patient numbers—the numbers of samples that we're going to expect—budgets and cost analysis. The science applies every day. Although as program manager, I don't serve as the technical lead on these projects…I still have to have a good foundation in my science—biochemistry, molecular biology and chemistry—in order for me to accurately write, convey messages and hold efficient meetings."

i. Learning technical skills necessary for the biotech industry

Participants in the study who are working in the biotech arena credited learning the math, science, and engineering principles that they use in the workplace from a broad range of places including in middle and high school, in their internships, through research experience in college, and on the job. Several participants explained that for them, learning was a continuous process that often began with learning basic math such as algebra in middle school and high school, and continually built as problems became more complex through college and on the job.

Most participants noted that while they learned the foundational information in school, they learned the math, science and engineering principles specific to their workplace on the job. Several pointed to having strong mentors or having on-the-job training such as technical presentations or collaborative group members, while others said that they were self-taught.

When asked what they believed to be the critical factor in being able to use the math, science and engineering principles, participants gave many, diverse responses. Paul noted, “I really enjoyed learning in the context of the problem they gave me.” Andrew expressed the driving desire to contribute to the field. Several participants pointed to a mentor who took great interest in the participant’s learning, while others expressed an imperative that they had to learn the new skill simply in order to effectively do their job.

ii. Problem-solving in the Biotech Industry

Because drugs are regulated by the Federal Drug Administration (FDA), participants in the biotech industry identified problem solving in relation to getting a drug approved which included assay validation, connecting with the various scientists and engineers to make sure that all requirements are being met, identifying possible sources of error, or locating missing data. Several participants mentioned that because problems are more ambiguous in the “real world”, STEM professionals need to have an understanding of the various components in order to “connect the dots”. Many were frustrated with the artificial problems given in the academic setting, and expressed the need to be able to apply theories to more real world applications. Andrew noted,

> I had some exposure through the lab courses and then undergrad research. But it was definitely different. It is a different type of cells, and more like manufacturing type of things like opposed to lab work. It's not the same as having a lab manual like in undergraduate. In the job setting it is more like, ‘Well, that didn't work. What are we going to do now?’ More ambiguity, uncertainty.

Participants pointed to learning problem-solving skills in the biotech field mainly through strong mentors or supervisors. One participant noted that his supervisor provided a combination of giving guidance and letting him figure things out for himself, letting him make some mistakes and then giving feedback in a kind, helpful manner.

b. Computer Software industry

Early career software engineers and computer scientists described their jobs as including designing software, coding, validation, and testing the product. All of these tasks require a solid understanding of computer science principles and an ability to use those principles in complex, uncertain conditions. Participants discussed that a "good" design is one that is maintainable and meets the requirements of the customer. Kevin noted, "I'm always trying to think about what it means to have a good design and how it's going to fit into the existing code base." Good design also includes a level of efficiency that comes from writing code the right way to avoid having to go back and re-write it, or so that others could read and modify the code independently. Nancy remarked, "The code I write will be consumed by different parts of the project or even by different teams. So it is important to make your solution simple and maintainable so that others can easily use or pick up where you left off to extend it. By following the principles myself, I am able to help influence others to do the same."

In describing the scope of how he uses his computer science background, Mike explained, "I write code all the time. I wrote 5000 lines of code last week." In addition to being able to use these core principles, some participants discussed how statistics play a role in software field. Mike went on to explain that his company was very "metric-driven." He noted, "we reference something all the time called the P-90, which is 90% of your data points…like what is the P-90 on how long for you to serve these requests? So 90% of the time, it takes one second to answer this question. That's something that is really meaningful to us. So understanding what that means from a statistical perspective is very important because if you start manipulating it in weird ways, you can get really weird data and that can make you think one thing, that isn't really valid."

i. Learning Technical Skills Necessary for the Computer Software Industry

Participants working in the computer industry pointed to a variety of ways that they learned the math, science and engineering principles necessary for practice, beginning with having a strong math background from middle and high school year. Several participants commented that they felt well-prepared in math. Mike noted, "I had had a great foundation in math from middle school and was able to compound on that. I believe that has set me up to succeed in math for the rest of my career."

For computer science knowledge, most participants pointed to specific college classes that prepared them for their jobs in the workplace. These classes included Programming Methodology and Design Patterns and Data Structures. When commenting on the Program Methodology and Design Patterns course, Kevin said,

> I think of every class I took, that one has been the most helpful in my career thus far. It gets you to think about software as a global thing. Most projects that we did were little simple programs, but you actually start with something that someone else built and you add these functionalities to it. So it really gets you to think about, there's this new thing, there's this existing thing, how do I make this fit and work? At least for me, it really got my way of thinking to change and be much more design oriented and not just, if I put in A it gives out B. It's much more of the big picture, which I think was a changing point for me in my academic career.

In addition to classes, every participant in the study who is working in a computer-related career pointed to their internship as a place where they were able to build upon their classroom learning, especially in specific areas that were not taught in school. Greg noted that, "I learned programming methodology and design at UMass, but I learned web applications through my internship and on my own."

Mike credited his learning to the experiences he had in M5. He noted that it was in M5 that he was able to take ownership of a project, be curious, experiment and make mistakes. He commented, "I learned probably more from my mistakes than anything else. Like writing [programs] and then writing them again when I realized there were better ways to do them."

Upon reflection, he noted that the critical factor for learning coding skills was a full immersion in the programming language. He stated,

> You need to know data structures like the back of your hand, because when you sit down to write something, you shouldn't be thinking, 'which data structure makes sense?' It's like writing words. I wouldn't think of using the work 'uncle' in place of 'aunt' when I'm writing a sentence. Like it wouldn't make sense, right? Like when I'm learning the English language, you might do that. You're thinking in that logical space and that language. It really comes down to like when you are learning a foreign language. Sometimes it's easy to make that mistake because it's so similar. But once it becomes natural, once you can think in that space, you wouldn't make that mistake.

ii. Problem Solving in the Computer Software Industry

Problem solving in the computer industry includes both front-end design problems such as determining the scope, parameters, requirements, constraints, and level of complexity as well as debugging once the program has been written. Participants expressed that learning how to problem-solve evolved over time, from being able to tinker with computers in childhood to skills-building in high school and college, through solving more complex problems in their internships and into their careers. Specific college courses were a critical factor to learning the computer science skills necessary for the workplace, but the types of problems they encountered increased in complexity as they entered the workplace.

Several participants noted that they learned problem-solving skills through being able to try new things without worry of negative repercussions. Mike commented, "I think exploration matters. Maybe that's part of it. One thing that I notice in people who always have a hard time keeping up, are people who are afraid to break things. They're afraid to try different things and explore." He went on to say that as a student working on a robot project in M5, he was able to explore and try new things that were of interest to him without the pressure of being graded. He remarked, "This was the problem that I wanted to create for myself. I feel like …a lot of time with classes, your problems feel really, really artificial. Whereas working on Emma (robot), the goal with Emma didn't really matter. People would be like, 'What are you going to do with this robot?' I was like, 'I didn't get to that. I don't know.' But the problems that you have to solve are awesome. It was still trivial, but it mattered to *me*! That's the point. It has to matter to you, for you to invest the time in it."

c. Commercial Products Industry (Manufacturing)

Those working in a manufacturing environment described their use of math, science and engineering principles as being foundational. Marco noted, "I use physics and a lot of engineering principles like torque, horse power and speed." Another participant noted that he uses math and chemistry to design experiments, calculate surface area and perform unit conversions. Several participants commented on the importance of having a solid knowledge of material science in the manufacturing of industrial products like transmission or aerospace components or in the electroplating industry. Participants use this knowledge both to affect performance such as increasing hardness, providing conductivity, or resisting heat, and in determining costs of manufacturing and longevity. One participant noted, "You need to understand the type of material you need, but also the cost and benefits of using different types of materials to product different products." Other participants spoke about the need to understand engineering processes and manufacturing techniques such as machining, testing and process improvement in order to perform the job. For these STEM professionals, math and science principles were seen as building blocks for learning the specific hands-on skills necessary for their industry, and from a business perspective of manufacturing products with both a time and budget constraint.

i. Learning Technical Skills Necessary for the Commercial Products Industry (Manufacturing)

Participant responses varied in how they believed they learned the skills and competencies necessary for working in a manufacturing environment. Marco credited learning the skills through his college courses saying, “Definitely the big help was the classes here at UMass, starting from materials class to manufacturing. It was definitely difficult in manufacturing class to actually, you know, you’re looking at things in a book. And going into industry you’re looking at how things are getting done. It’s definitely different but it was something that wasn’t new to me. I could see these regular workers working on different machines and be like, ‘oh yeah, I saw this in my manufacturing book’ and I can actually go back to it and relate to it.”

Other participants, however, credited learning these necessary skills on the job. These participants recognized that while they had not learned the specific skills they needed in school, they did learn how to apply the math, science and engineering principles to their job. Ian noted, “nothing I specifically learned in engineering, like I didn’t learn how to calculate the time of an electroplating bath, but I learned how to learn.” Travis pointed to a senior machinist who served as an important mentor. He noted, “One mentor really took the time to sit down and answer any question I had. He was always open to answering the questions. Especially because he’d been in this field for 40 years, so he just knew everything about drills, you know. That’s not something a lot of people think is that important, but this guy knew *everything* about drills!”

ii. Problem Solving in the Commercial Products Industry (Manufacturing)

Participants identified two distinct types of problems that arise in the manufacturing environment as technical problems and interpersonal problems. Technical problems involved issues with manufacturing equipment, quality control of products, or supply chain problems.

Travis described a problem at his aerospace manufacturing company in the following way: "So, as a job-shop, we always had different parts to make and the machinist would be running it, and the part wouldn't be coming out the way it was supposed to. And it's not simply an issue of, 'oh, you just need to adjust the tool.' It was suddenly this part was distorted. What's going on? And the answer is, 'nobody knows,' Travis, go figure it out. There's no right answer, you just don't know. The right answer is 'make it work'."

Interpersonal problems included those that arose in dealing with customers and in working collaboratively with technicians or machinists. In dealing with a customer, Marco noted, "We would get a lot of, you know, customers with their own ideas. And I would have to go through them and see if they actually make sense. And if they aren't manufacturable, I would have to call them and see if they could buy into it. Otherwise, we have to say, "We'll make it for you, but we aren't responsible for breaking." So we try to communicate as best as possible. Our best word to use is 'we suggest.' We never recommend, but we suggest."

d. Commerical Products Industry (Research and Development)

Those participants working in research and development (R & D) placed a heavy emphasis on the importance of understanding and applying math, science and engineering principles in their daily work, noting that in dealing with highly complex environments, you need to have a combination of this knowledge and be able to apply what you know to uncertain situations. Dan described his work as understanding and applying the science and engineering of interacting surfaces in relative motion, which includes the study and application of the principles of friction, lubrication and wear. "This includes a lot of testing, predicting patterns. You have to use your knowledge of materials, chemistry, and also physics." Paul described his heavy use of math, science and engineering principles in his work with audio processing. This work included writing algorithms, using physics, and high-level math. He noted, "We do all of the actual audio processing. We take the audio as a signal, you know a stream of bits, a stream of data, and we end up doing stuff to it. And what we do to it is dependent on different situations, but it's really the software portion of audio processing, or audio in general, really. So it's a lot of math, a lot of math., which is great. That's actually one of the reasons why I wanted to go into this field was because I really missed math. I'm doing integrals all the time."

i. Learning Technical Skills Necessary for the Commercial Products Industry (Research and Development)

Participants doing research and development described learning the math, science, and engineering principles needed for practice from a wide range of places including specific courses such as Introduction to Communications, Digital Signal Processing, and Senior Lab. These participants also mentioned learning through their internships or in M5, as well as on the job and things that they self-taught. Paul noted that having the opportunity to work on "fun" projects outside of class, through M5 was a critical factor in learning the most important engineering skills that he uses on the job, embedded systems. He noted,

> Most of the stuff that I really ended up wanting to go down the paths of were not so much because of classes, they were more just from obvious applications--just wanting to learn something because it seemed interesting and exciting. And really for me, embedded systems falls into that category because I didn't take any classes that taught me things directly related to embedded systems. And that's what I'm doing primarily.

When pressed how he believed he developed this skill, he responded,

> Other students were a great part, actually, especially coming from M5. A lot of the paths that I ended up taking to learn things in M5, and the stuff that I ended up learning were from the motivation of other students. Other students were working on something and I'd say, 'oh that's cool' like, let me learn more about that. Almost all the embedded systems learning I have really came from M5 and from other students in a lot of ways.

ii. Problem Solving in the Commercial Products Industry (Research and Development)

Participants in the study described problem-solving in the R & D sector in a variety of ways, including: characterizing materials necessary for developing a new product, optimizing a process so that it could be scaled up to a manufacturing level, predicting how a material or product will perform under specific conditions, trouble-shooting a problem or adding a feature to an existing product. Participants expressed the need to combine foundational knowledge with creativity and a willingness to try new things in order to push beyond the boundaries of current technologies. Paul noted, "You have to be able to thinking differently--not just regurgitate things but making sure you actually understand the principles that lie underneath." However, he also noted that in development, "Sometimes you have to guess--try what you think is best. You can't be afraid to try something." This combination of applying foundational knowledge with a willingness to be creative was a common theme among participants. When asked how he learned this skill, Dan explained,

> I think senior lab might be the perfect example of this. You are given these problems that are complex enough that you can't really predict what the results will be. So oftentimes you go to class, you're given a project. You kind of know what's going to happen because it's based on what you've learned. You don't know the answer per se, but you know how you're going to approach it. But for something like senior lab, it's too complex to be able to do that, so then it requires you to think differently and make sure you understand the principles that lie underneath the objective of the project, and make sure you keep engaged as you do the tests and experiments. So that was especially useful in my current job because I don't know what's going to happen, so I have to keep questioning things.

<u>e. Data Analytics-Related Industries</u>

Four participants in this study are working in analytical positions that cross a broad range of industries including defense, insurance, energy and government. Two of these participants majored in mathematics; one majored in aerospace engineering, and one double-majored in math and electrical engineering. These participants are using their knowledge of math to do cost analysis, build energy models, conduct large surveys, and do probability-based analysis. The two participants who majored in math explained that they did not use high-level math or other scientific or engineering principles in their jobs. However, they both use various computer software packages and described needing a strong background in problem-solving skills. The other two participants, however, described needing an understanding of how processes work and having a strong foundational understanding of the science and engineering principles such as fluid dynamics, materials science, thermodynamics, heat transfer, mass and energy balances, and electronic systems. For example, Caitlin described her work as developing models for energy transmission systems. To do this work, she needs a background in both science and engineering including basic circuitry, electrical engineering, and physics. She applies these principles in designing generators, understanding different fuel types and comparing emissions. She also conducts economic studies by simulating power systems. This work requires the use of Monte Carlo simulations and statistics.

i. Learning Technical Skills Necessary for Data Analytics-Related Positions

While most of the participants reported that they had strong math background that they learned from childhood through middle and high school, Caitlin felt that her math skills, especially in statistics were not strong enough after needing to use this skill during her internship. As a result, when she returned to college after her internship, she chose to add a second major in math. She noted that she learned many of the core principles she needed through college courses such as physics, electrical engineering, computer programming and power systems. Many participants pointed to their internships and jobs as the place where they learned the specific skills needed for their industry. When asked what the critical factor was for being able to perform her job as an actuary, Ashley responded,

> I think for me, its curiosity. It’s tough because I can’t imagine myself without having some computer knowledge-base. I don’t know what that would look like. I guess I

> would say if I never took any programming classes, if I never took any math classes, I never would have been successful. But given that I had the prerequisites, the number one thing, I would say is curiosity. It's like, why does it work this way, why am I being told to do it this way, why can't it be this other way?

ii. Problem Solving in Data Analytics-Related Jobs

Problem-solving for participants in this industry sector focused on being able to obtain adequate, reliable data. Two of the four participants worked for major, national agencies, the third participant worked for a regional energy non-profit agency, and the fourth participant worked for an insurance company. For each of these participants, data collection was a key component of being able to successfully perform their job, whether in developing an energy model and collecting energy and emission data from various power generators, to determining the cost to build and maintain a new search and rescue airplane for the armed forces, to collecting wage and benefit data for a national database, to developing predictive models for insurance claims. Megan noted,

> In my job collecting data, the most common problem is response. So in order to keep a quality amount of data we need their participation. There's all different ways for them to refuse to participate, and the first step is identifying what the reason is. Sometimes it's because they don't have enough time, sometimes it's because they just don't want to participate in any thing voluntary, the company might have a policy. Other times it's because they don't want to give the government any information, they have trust concerns.

<u>f. Public Works: Design and Construction Management</u>

A final category in looking at how early career STEM professionals use math, science and engineering principles is that of design and construction management. Because many construction related projects require the stamp of a professional engineer—a process that takes between four and five years and results in a professional engineering licensure—an early civil engineering professional is limited in the type of work that he or she may do. Tim described his work in water main and water storage tank design. "The design that I work on is more of a setting up of general guidelines, specifications, that sort of thing which the final design has to conform to. And in addition to design, I'll work on construction administration, so I'll be out in the field-not all the time, but maybe a couple of days a week, watching how it's going, overseeing that." He explained that he rarely uses his math background except for doing basic calculations in spreadsheets. He does rely on his understanding of how water treatment plants work, of technical specifications and government guidelines, and analytical problem-solving skills.

i. Learning Technical Skills Necessary for Public Works: Design and Construction Management

Tim pointed to several key factors that contributed to his learning the skills he needed to be successful in the workplace including two different internships and two specific classes. One class included a small water-related project where he designed a water main. A more important influence, however, was a field trip to a local water/waste water treatment facility. He noted,

> He took us on a field trip to one of the Amherst water treatment plants…that was huge because you see pictures of things, and you see things on power point slides, and you see them in a book, but when you actually get into the building and see how it all works, and [the professor] has a good relationship with the people who work there, so he got them to backwash their filters while we were in there, which was a really cool thing to happen.

ii. Problem Solving for Public Works: Design and Construction Management Jobs

Tim noted that problems in this industry are usually related to design. "How can you design this facility so that whatever is there already isn't going to be damaged, so it can still be used during construction, so that all the requirements of the client or the owner of the facility are met." He went on to say that usually, this means, "making sure you have all the information: from clients, from drawings, etc. Problems often arise from missing information."

2. Learning Outcomes c, d: Communication Skills and Teamwork

The ubiquitous need for good communication skills was expressed by all the participants in the study, being described as, "the most important part of the job", "pretty much #1-both orally and in writing", "a huge part of the job", "crucial", and "super, super key". Andrew remarked, "In science and technology, your ideas are useless if they are trapped in your own mind. It is imperative that you are able to communicate well to be able to get your idea off the ground."

a. Verbal Communication Skills

For participants in the study, oral communication included explaining technical information, answering or clarifying questions, pitching ideas, giving feedback, formal presentations, proposing solutions, asking for help, code reviews, design reviews, assisting and training others. These skills were used across the range of environments from small group meetings, one-on-ones with colleagues, phone calls with customers, video conferences with managers, to presentations to the CFO or clients. Participants noted that communicating well with colleagues and customers across multiple backgrounds and educational levels is essential in being able to do their job effectively. Kevin noted, "When you're assigned a task, you need to be able to communicate how long it's going to take, what it's going to take to fix it, what the risk is, things like that. So, I think in terms of my daily responsibility, that's probably the most important." Similarly, Dan remarked,

> Some of the projects I'm involved in have many different people that have their own parts that end up contributing to the project. But then each of these pieces might be in competition to each other. Let's say you're given a work packet, you can't just work on yours and then be done. You've got to be able to communicate what your finding is to other groups so that they can better understand what their results are like…so you want someone to do the test, to be able to tell you what's important and what's not, so you focus on the right thing, and if you don't, and other people look at your data asking questions that you can't answer, that creates all sorts of problems.

In addition to describing how they use verbal communication skills, many participants noted how these skills require an understanding of the audience and the differences in educational levels and technical backgrounds. Ian noted,

> When I explain something, I have to explain it to my managers in 30 seconds in the hallway when they ask me a quick question, I have to explain it to the operators on a level that they can understand appropriately, and I have to explain it to the engineers who don't share my background in chemical engineering. And I have to explain things well to them when they're seeing something that they're trouble-shooting.

Several participants also commented that time constraints are an important consideration when communicating with others, especially when giving presentations. Ian went on to say, "I had to communicate effectively. Because I may have only been given a half an hour meeting trying to bring these people together so I had to be able to get my point across, but also be able to do it well, do it efficiently." Chris noted, "It's being able to convey the message. It's knowing your audience. If you have top executives in there, their time is sensitive so you want to get to the point and make this clear because often times a CFO doesn't care too much about the technical details. They want to hear how the project is progressing, are we on budget, things like that. So for me it's being able to communicate across all levels efficiently and effectively."

b. Written Communication Skills

Written communication was also an important component for all of the participants. These skills include writing technical reports, documentation, field notes, lab notebooks, email, summary/business reports, protocols and standard operating procedures, and meeting minutes. Tim noted, "Notes are incredible. You need to take notes, especially when you are in the field. This is a huge deal—any field notes that you have as a resident project representative are legal documents. They can be used in court. So you need to take good notes, proper notes. You need to have all the correct information." Caroline noted,

> Those skills are extremely important in science. When I was a lab manager, I was responsible for writing up all the SOPs and doing the training for a lot of pieces of equipment, and so that was really important, so sort of being able to convey not just effectively but concisely. People won't read more than one page. So you can put the manual for a piece of equipment there, but nobody wants to bother with it. That is actually a skill in which a lot of people in the field are lacking.

Several participants explained that good documentation and writing skills helps to save time in later trouble-shooting or when dealing with colleagues or clients. Paul remarked,

> Time saving is a huge chunk of that. If I don't actually document things that other people will be using in the future, well, whether that's commenting things through code or actually writing technical documentation and publishing it somewhere. It means that if anyone else needs to use that system, they will have to discuss it with me for far longer than I would like to. I would much rather hand things off in a way that other people can end up using them and figuring things out for themselves just through the documentation.

Similarly, Kevin noted,

> In terms of coding, at least from my team, I'm one of the only people who actually puts comments in the code, which drives me crazy. I think it's essential. You want your code to speak for itself as much as it can. Name variables in a way that makes sense, and not like A-1, B-2, something like that, because you look back and say, 'what the hell was I thinking!' But then, on top of that, for myself and for the rest of the team, I know that I've written code and was rushing and delivered it and didn't put in comments, and then it turns out there's a bug in there, and I'm looking at it and I'm like, 'why did I do that? I remember there was a specific reason I did it this way. I did this because internet explorer doesn't work if you do it the logical way, so we have to work around it, blah, blah,' but I didn't put that in and spent, whatever, a day. Wasted a day of my time trying to figure it out.

i. Learning Communication Skills Necessary for the STEM Workplace

Communication skills were learned from a wide variety of places, beginning with parents and in the K-12 environment. Several participants noted that it was "just their nature" to be outgoing and communicative, but were able to practice and improve these skills with the help of family, friends, and teachers. Mike noted,

> I've always been a chatterbox…my mom would guide me to better communicate my ideas. I think my ability to persuade people and that kind of communication was growing up with my sister. Me and my sister never fought, we got into debates. We got into long debates and she was really good a being right most of the time. So learning

> how to manipulate words and present ideas in different ways and convince people to agree with one thing that they think they don't agree with until they realize they are agreeing with you. That was learned from being a kid and arguing with my sister and trying to win debates over stupid stuff.

Ian pointed to a high school teacher who encouraged him to have strength in his convictions. Ashley remarked, "English is my parent's second language, so there are some things I would need to simplify or find another way to explain to them." Others mentioned a high school public speaking class or a business competition.

Three of the participants pointed to the iCons program as being important in learning higher-level communication skills. In discussing technical presentations, Brian noted, "the iCons II communications things were very, very helpful. We focused a lot on what makes a good presentation, what makes a good slide, what makes a good figure--and working and making those. Working on all those projects was definitely good." Brian noted that in iCons there was a heavy focus on technical writing and group conversation. Other participants pointed to senior design projects, tutoring, serving as a campus tour guide, being an officer in the biochemistry club, M5, and the junior writing class. Tim noted, "Steve Constantine. He's one of the best professors *ever*. He was so good at teaching you how to be a technical writer. It was the only 8:00 a.m. class I ever looked forward to in my entire college career. I loved going to that class. And it was a *writing* class. Who likes writing? But it was a great class. I learned so much, so much."

Other participants did not feel that they learned oral and written communication skills in college but learned them through their internships or on the job. These participants pointed to company-sponsored courses on effective communication and excellent mentors who provided useful feedback. Megan noted, "As a math major where it was very independent unless you seek other students out to collaborate on homework assignments or something like that, it could be very isolating. You know, no presentations, no persuasion, so I didn't learn that in school, but in both of my internships I gave presentations." Tim added,

> During the internship, while I was in the field, that came from watching other people do it. Because I was tagging along with the other inspectors on their rounds, and I would see how they would interact and every once in a while I would cover for someone who was on vacation for that day, and I would be out there myself and an issue would come up and I would just mimic what other people had done.

Caitlin commented that her supervisor had helped her improve her technical writing skills, noting,

> My current supervisor was huge in that. He would edit it but not only would he do that we would go over it and sometimes the things he would say is like 'oh, this is nitpicky but there are possible different interpretations maybe, that's why we need to change it.' So he'll explain why it was necessary. So the mindset is I can learn what the different perspectives are when someone reads the same sentence. But that really drilled in I need to be more mindful of what other people see. So I'm very sensitive to miscommunication.

ii. Challenges in Communication Skills

While some participants credited learning the communication skills necessary for the workplace at home, in school, through their internships, or on the job, several commented that communication skills, whether written or verbal, were their biggest challenge. Two participants mentioned getting angry at work and wanted to have more conflict resolution skills. One participant noted that he sometimes talks too fast or talks over himself and isn't able to explain things clearly to his supervisor. Ashley mentioned that she was not a good communicator, but learned from her mistakes when she saw a similar negative behavior in her supervisor. She noted that as an only child, she didn't have to think about how she said things. However, on the job, she began to receive complaints from colleagues and clients. She noted, "For the first 22 years of my life, it never occurred to me that, like, 'hey, imagine yourself as the listener. How would you react to this person? You know that you wouldn't put up with this person." Chris remarked about his writing skills,

> Writing is definitely my weak area. I've always been math and science oriented, so throughout high school I was terrible at writing, I mean I got decent grades, but math and science came easy to me but writing—I hated it so I kind of shied away from it. I didn't do all that much writing in college. I think, honestly I tried to choose classes that didn't have that aspect to. That writing in biology was my junior year class and that class was absolutely terrible. Oh man, it was miserable for me. It's just not my nature.

When asked about his communication skills, Mike remarked, "That is still super hard for me. It's something that I struggle with in general. And it's partially due to my assertive personality…and being loud—that's what I am. I feel bad when I do it. Other people's ideas matter to me. But I get excited what I'm talking about, and other people take it like, 'oh he's just dominating the conversation, he doesn't care about my opinion.'" Ian pointed to a particularly hard lesson he learned in presenting ideas efficiently at a meeting. He recalled,

> I blocked off about 30 minutes for the meeting, and I noticed that I was running long--probably about 45 minutes to an hour. And then eventually one of my general managers actually just got up and left. He goes, 'I have to go to a different meeting.' And …my manager came up to me and said, 'hey Ian, you need to parse things down, you can't go into that length. I know you want that, and you want to be able to share all these things with us, but you need to kind of clean it up.' So that was a little jarring.

c. Teamwork

Closely tied with communication skills is the need for early career STEM professionals to be able to work well in a team environment. For participants in the study, immediate teams ranged from very small three-person teams, to large 30-person teams with extended teams up to 60 members. Nancy noted, "We must be versatile to be successful on the team by learning, building, and connecting with other development teams internally and externally." In addition to other engineers, mathematicians and scientists, team members included technologists, analysts, project managers, plant managers, operations managers, developers, testers, laborers, machinists, scheduling experts, contract specialists, clients, sales people, business managers, economists, government regulatory specialists, lobbyists, students, and lawyers.

Some of the participants in the study mentioned working on multinational teams. One participant's team included members from the United States, Taiwan, Netherlands, Egypt, France, Israel, China and India. In talking about his team members in Romania, Kevin noted,

> It is difficult when we get in the morning, they're finishing up their day and by lunch time they're long gone. So, we do have daily scrum meetings every morning so that the team can sync up what everyone did that day, what problems they're running into and what they're going to be working on the following day. For the Romanian team, it's all past things—'this is what I worked on yesterday.'

Educational levels on participants' teams included high school level, bachelor, master and doctoral. Most of the participants discussed the organizational structures of their teams including peer-to-peer team members, people in supervisory roles such as managers, and extended team members in tangential roles such as regulatory personnel or clients. Some participants also included team members who were in more subordinate role, whether officially or unofficially such as machinists, technicians, or construction workers. While most of the teams were interdisciplinary, some teams were extremely homogenous. Ashley noted, "Everyone is either an actuary or a statistician." Caitlin described her immediate group as "all engineers" with her extended group as "mostly engineers but also technical analyst." While participants in the biotech, computer, research and development, and math-related industries described teams that included both male and female members, participants from the manufacturing industry described their teams as almost exclusively male. Team power structures ranged from extremely collaborative with shared decision-making to more hierarchical structures. Caroline noted, "We're working on one project with a specific goal. Not just one person telling another person what to do. We help each other." While Kevin noted, "I decide how the general design should be then hand it off to someone else to implement."

i. Learning Teamwork Skills Necessary for the STEM Workplace

Participants described learning teamwork skills through a variety of ways including in their families, through organized activities such as team sports, band, and scouts, in college through design teams, the iCons program, M5, and student societies or clubs. Outside of college, participants reported learning communication skills during their internships, and on the job. Nancy noted, “Growing up with three other siblings, we were always together, so I learned how to compromise as well as ask for help. We’d often split chores or tasks to be done because everyone’s skill levels differ depending on the problem at hand”. She went on to say, “My parents always encouraged teamwork, and with a big family it's important to stick together”.

In college, participants pointed to specific projects or activities that helped them develop good communication skills. Marco described a professional conference he attended for the Society of Hispanic Professional Engineers. He noted, “We went to a regional conference and I was part of a bunch of different engineers and a group of about ten. It was a challenge where we had to build a robot in twenty four hours. That one gave me the chance to see how to work with strangers as a team and not to butt heads”. Mike recalled learning teamwork in M5 while working on an optional controllable robot project called, “Emma”. He remarked, “It was a group project with different people working on different things. There were periods that were very team oriented and periods that were just me doing my own thing…we worked together because we were all interested in the project—it was fun”. Tim pointed to a college project in Brazil through Engineers without Borders. He recalled,

> We had two people who were fluent, but nobody was actually from Brazil, and the language changes depending on where you are. And then once we had the materials, we had to get the water pump working, and then we had to install it in the middle of the Amazon with very limited resources. We all had to work together incredibly well. We became a good team over our countless weekends here at UMass perfecting this water pump. I came up every single weekend that summer to work on this water pump. So, we became a good team here, we developed a good working relationship. Everything like that, and then once we were actually in Brazil, it all panned out.

This concept of building teamwork over time was echoed by several other participants. Dan recalled how his understanding of teamwork developed as a college student through the iCons program. Reflecting on his progression from being critical of other team members to valuing the importance of a multidisciplinary team, he remarked,

> I was exposed to many different ideas in tackling problems, and I guess because it was the first year, I think a lot of us were kind of, sometimes, not open to some of the ideas--like we thought it was stupid, like so dumb. I don't think anyone said it out loud, but I know that I was thinking it when I was hearing some of the stuff, like you know it's not feasible, or you think it's not feasible. Once we got to the junior year, I think we were trying to help each other come up with thesis ideas and we were put into groups, and while we were conducting difference research, we were meeting regularly to advise or help them relate to the iCons theme—making it more interdisciplinary and connecting it to real world applications, bring it to the big pictures. But for that, it was really helpful to have people from different disciplines.

Kevin noted that learning teamwork has been a "gradual learning process" that has grown since coming into the workplace. He commented, "Once you get into industry, and having to interact every single day with people, the success of your product depends on you being able to communicate your ideas effectively with members of your immediate team so that they understand." He went on to say that these skills have not always been easy for him, and that he has learned from mistakes to improve both his teamwork and communication skills. He went on to say,

> It's been progressive. It's gotten better. I would just say, 'well, here's the task, this is what we need to do, any questions?" And it would be like, 'no, not really.' 'Ok, go do it.' Then we'd have a code review and I would be like, 'this is not at all what I envisioned! I don't think this is going to fit well into the overall design.' So then I would have to spend addition time correcting my mistake and their mistake. And they would have to spend more time re-doing what they had already spent days doing because I wasn't clear. So, I've been very apologetic and asked for feedback when things aren't clear. Because to me, it all makes sense to me up here (points to head). It all makes sense in your head and then sometimes you find yourself trying to explain what you're thinking and you're like, 'uh, I'll get back to you.'

Several participants were adamant that they did *not* learn teamwork skills in college and pointed to this as being one of the most important skills that they wish they had learned. When asked to reflect on why they believed they did not learn this important skills, participants pointed to a variety of problems. Dan noted that teams that were self-chosen didn't teach him how to work with people from different backgrounds or different perspectives that he encounters in his workplace. He noted, "Everyone knows how to discuss things with their friends that they see every day anyways. It's having to work with people of different backgrounds that have different priorities than you, have different frameworks, things like that." Some participants commented that teamwork in college didn't work because the project "seemed contrived, not real." Other participants expressed the belief that one barrier to teamwork in colleges is that students don't all have the same standards. Chris remarked, "We did have team-based labs and especially in the later stage of your academic career. You don't really learn. You just kind of get lumped into the team and you get down to the point people just care about the grade and getting the work done, so I wouldn't say that any type of teamwork was learned, actually." While Tim noted,

> In terms of teamwork, technically, in school and stuff, that was kind of forced down my throat. In school, I was always someone who would rather do a project by myself than work with a group of people, because I had my own standards and I wasn't positive that everyone else would meet those standards. It was just a hassle to work on a team in college and in high school, but it's forced down your throat and you have to do it, and that's a learning experience too, so you have to end up working with people who you may or may not want to work with, and you have to do that all the time in the real world.... The company has standards at work...in the workplace it's not an issue of having people who aren't as dedicated to the work as you are, because really, everyone is.

While all the participants in the study noted that teamwork skills were very important in the workplace, several participants acknowledged that teamwork skills were extremely challenging for them. Most often, the difficulty in teamwork was linked closely with the challenge of communication skills. Several of the participants who worked in the manufacturing sector commented on a lack of experience working with blue collar workers such as machinist or technicians. Travis remarked,

> The biggest thing…was I had to learn how to communicate with the blue collar laborers out in the machine shop. Had *no* experience, *no* idea how to handle that… I was not in the management chain of command per se, but I was their supervisor at the same time…Part of the job was getting everyone to work effectively, so if somebody keeps having problems, you need to be able to work with that team member and figure out what their needs are to make it work.

Similarly, Dave noted,

> We all know what our individual roles are to get a successful study. But, if you don't know what that study is working towards, like what your end result is going to contribute to—are you going to work as hard to make sure that everything's done correctly? Or if you know the end result is going to before filing for a product to get people the medicine they need, it might give you a little bit more encouragement to do a better job. So if you're communicating both what the needs are of the goal and what the goal will contribute to, I think that leads to the most successful teamwork.

He went on to say, "The biggest downfall for running these studies is if people aren't privy to what's going on around them. A lot of times people are waiting for this information to make these decisions. And if these decisions are being made in a vacuum, how are we going to know what the next steps are. So for me, communication is number one."

ii. Critical Factors in Developing Teamwork Skills

There was a broad range of critical factors that contributed to participants learning teamwork skills. For some, effective teamwork is an essential component to just doing the job, noting that these are very difficult problems that you can't solve alone. Dave remarked, "You need to be able to talk to all these different levels of people with different expertise in order to get the job done." Others pointed to good managers who also served as mentors. Caroline noted, "A lot depends on the manager. He or she sets the tone for the interactions (on the team)." Several participants mentioned the need for good teamwork in improving efficiency with their work. Nancy noted, "Teaming up meant that the assignment can be finished quicker with a division of tasks, and I would have the chance to learn something new if someone on my team is skilled in an area that I need help on." Other participants linked good teamwork skills with being successful in their careers. Caitlin remarked, "If you're a jerk nobody will ever give you a pat on the back, because they'll say, 'you already think you're all that.'"

Other participants expressed the idea that working toward a common goal is the foundation for good teamwork. The critical factor that was mentioned by several participants in the study was the notion of balancing being a team-player and being an individual contributor. Paul noted,

> Understanding that you're part of a team is probably the biggest part of it. I've seen people who felt as if even though they are on a team, as long as they really do their portion very well they do not have to be interacting or helping out other people nearly as much. And those teams usually do very, very poorly-very, very poorly. So even if the person is incredibly intelligent, they often just do not work out well on teams. A little bit of empathy goes a long way. I've spent a lot of time just helping out other people, sometimes with things I think are very simple, I find that if you just help them out for a long period of time, make them feel like they *can* contribute, they end up actually opening up and contributing.

Others, however, disliked being asked to help others so often that they were unable to complete their own work. These participants pointed the ability to prioritize work as a critical factor in being a good team player. Caroline expressed the idea that because people work and think different, it is important to be flexible and to recognized that there are varying communication styles on a team. She noted, "I think a lot of getting along as a team is knowing how the other team members operate, because not everybody is the same, and that can lead to challenges because, I think, in that instance communication is not always delivered in the same way, so I think there can be issues."

3. Learning outcome e: Understanding ethical and professional responsibility

Participants in this study were reflective, thoughtful and passionate in describing the role that ethics and professionalism played in their jobs. Participants who worked in fields that were directly linked to animal testing, public health, and safety, such as the pharmaceutical industries, genomic research, public works, airplane manufacturing, or national security, viewed ethical responsibility as a core component of their job. For these participants, working at the highest ethical level was mandatory because of the high consequences associated with malfunction or error. Ian, working for an airplane component manufacturing company, commented, "Professional and ethical responsibility—I'm reminded everyday of that. Knowing that what I'm working on is going to go into a plane that people are going to fly on. People's lives are going to be carried by this. And that idea just always centers me." For Ian, the consequences of doing the work incorrectly could result in "catastrophic failure." Working in the pharmaceutical industry, Kevin noted, "We're essentially developing a drug that's going to be administered to humans. So that's always in the back of your mind." Dave remarked, "We need to act professionally and use good ethics. I mean, for one, we're sacrificing animal lives for our studies so you need to be respectful to those animals and only use them if necessary."

Ethical responsibility also included the notion of safeguarding information such as trade secrets or intellectual property and maintaining client confidentiality. Whether wage and benefit data, patient healthcare data, or genomic data, human subject information must be protected and used in an ethical manner. Megan remarked, "Even just their identification has to be safeguarded because the sample isn't revealed. When you're looking at the wage and benefit data, you can't zone in what people are paying or who's giving what benefits. The sample is not public knowledge, so when you're gaining their participation, you're assuring them ethically that you won't reveal their identity or misuse the data." Brian noted, "The big thing is the human subject stuff, because we're dealing with real patient data—real genomes. And one thing that absolutely cannot happen is that this data absolutely cannot leave the [company] network. And that's because you know from a genome, if you know what you're doing, you can identify the person and so forth…everything is a person."

Similarly, participants identified how information was collected, analyzed, and disseminated as an important component of ethical behavior. One participant pointed to providing data to decision-makers, and making sure that data was accurate. He noted that in providing data, he must consider not only what to include, but what information to leave out, and what actions to take when there is a discrepancy with data. Caitlin disclosed a specific time when there was some inconsistencies in data that her company was presenting. Although within the “letter of the law”, the variance troubled her to the point that she spoke with colleagues and eventually her supervisor. She noted, “Some colleagues said, ‘well this isn’t a big deal, its fine, it kind of all meshes together.’ But I had a very strong feeling that it wasn’t.”

Other participants in the study viewed ethical and professional responsibility from the point of view of interactions with co-workers including colleagues, subordinates, clients, and vendors. These participants pointed to the importance of respect in verbal and written interactions, in being prepared so as not to waste others’ time, and in regards to workplace safety. Ian noted, “I’m responsible for my operations. If I have an unsafe process, if I design something improperly, or if I don’t calculate something properly and it overheats or leaks or breaks, that’s on me. That’s my responsibility. These people I work with everyday…They’re relying on me to help them do their job.”

Another way in which participants described their experience with ethical and professional behavior was in regards to just performing the work they are paid to do, upholding the policies and procedures, or advancing the mission of the company. Participants commented, “that’s what you’re paid for,” “do the right thing,” “not taking advantage of the company,” “have ownership of your work,” “need to operate in a sustainable manner,” or “be responsible for your work and your actions.” Chris commented, “They’re paying me, and I want to make sure that I'm not just taking their money. I need to make sure that I'm doing the work that they want to validate my salary and then also validate or confirm my responsibility to the sponsor."

a. Learning Ethical and Professional Responsibility

Participants reported that they learned ethical and professional responsibility from a range of places and people including parents, extended family, scouts, church, sports, specific professors in college, the career center, iCons, internships, and on the job. Dave relayed his experience growing up on a farm and his affection for animals as shaping his ethical approach to animal research. He noted, "I've always loved and cared for animals, so when I started working with them, I had that understanding that this work is *necessary*. So I never question doing the work and knowing that the work needed to be done and knowing that I cared for animals. I knew that I wanted to do the best job that I could so that I was providing them the highest level of care as well as getting sound data so you didn't have to repeat things."

Several participants pointed to a specific college professor who taught their junior writing course. Participants commented that this professor "really got me thinking" about the consequences of their work. Kevin noted, "He was amazing, and he really got me to think about software in a different way. That ethical question was never anything that I had even thought about. Software being [used] for harm. He always used to talk about, 'you need to be mindful of what it is you're doing and how it can be used.' The participant went on to say, "My product is very general use, you can use it for a lot of different things. Not necessarily for good things." Chris noted that he had *not* learned this skill in college. He commented, "There are no stakes in college. There's nothing driving a patient decision or critical project. I shouldn't say, 'nothing,' but often times the educational stuff—there's no risk involved. But when you're getting paid…Your company has taken on this project, they're paying you, they're trusting you to get it done. You have an obligation to that."

Many participants explained that they learned professionalism and ethical responsibility in their internships and on the job. Travis recalled a formative experience that happened his first day of work. He noted,

> I had a guy my very first day who was in tolerance of our engineering specs. So, we're measuring a dimension and it was in. And I said, 'ok, that's it right?' And he said, 'you know, it's in, but it could be better, and as Americans, I think we ought to make it better.' That blew me away…He wasn't saying that to just make a statement. He was saying this is American made and we're gonna get it on the nose. It's gonna be perfect, and he totally believed that. And I was like, 'Oh wow, that's awesome!' That job was all about, 'we make perfect parts here' and there's a lot of pride in that.

Caroline spoke of safe disposal of chemicals, noting, "There are some people that want to follow the rules and there are some people that are like, 'uh, I don't feel like it, and I'm gonna dump this down the sink.' And maybe it's not the worst thing, but it's not the right thing."

Other participants pointed to professional organizations or federal guidelines for ethical behavior that they are required to learn as part of their professional positions. For those working in the biotech industry, STEM professionals must adhere to Federal Drug Administration (FDA) regulations for production of pharmaceuticals. Participants in the study mentioned working within FDA guidelines for compliance on drug development. Chris noted that he must do, "everything in accordance to the current guidelines set by the government…to ensure the safety of the patient. And that's a message that's conveyed by the company, and that's the stake for us. Whereas in school, often times you're just trying to figure out the best way, the easiest way to get something done. In industry you need to check all the boxes." In addition to the FDA, participants discussed passing professional examinations in order to become an actuary or a professional engineer (P.E.). Tim noted,

> If something we do breaks, it's a public safety issue. So there's a pro and con of being a professional engineer. You have all the responsibility—you get to design and stamp drawings for massive projects—that's incredible on your record. But if something fails and your stamp is on it, that's on you. So the ethics of it—you learn a little bit about it in school, but I think it really comes around once you have to take that P.E. exam.

4. Learning Outcome F: Ability to Locate, Organize and Analyze Data from Multiple Sources

Participants in the study described the ability to locate, organize and analyze data from multiple sources as key component of their job, noting, “you pretty much just outlined my job,” “this is my day,” and “everything we do.” In general, participants use data in connection with solving complex problems. Many participants spoke extensively about the need to use data from multiple sources in order to “connect the dots” when making important decisions or determining the root cause of ambiguous, multifaceted problems. Paul noted, “Just about every problem is open ended. I’m always pulling information from difference sources to see what the best approach or the best solution might end up being.” Caroline remarked, “The company gets data from several CROs (contract research organizations) and examines every aspect of the data to determine which direction to go in their research.” Participants used the data to develop or improve processes or products, to create energy demand forecasting models, to provide a national database for wage and benefit information, to develop predictive pricing models, to carry out municipal infrastructure work, to obtain FDA approval for new drugs, and to develop genomic models for cancer research. Ian described starting a new laboratory for his company’s electroplating process facility in the following way:

> We didn’t have any equipment, didn’t have a lab. I needed to spec out everything. So, we had capitalized 1.25 million dollars, and I was handed that and was told, ‘go make this line, go make a process for this.’ So, then I had to say, ‘ok, what am I doing? How do I do this?’ It was a lot of learning. What kind of chemistry am I going to use? I don’t even know how to make this happen. What kind of equipment do I need on this? What kind of analysis equipment do I need? All this was coming from difference sources. It was anecdotally from people I had touched base with. It was from vendors that I was quoting with, it was from research—trying to find things online and sort of locating all that. I don’t think I would have been successful if I didn’t have *all* those resources available. I think if any of those resources would have fell down, there would have been a big gap.

Mike talked about his project developing an online catalog. He noted,

> So literally, we're getting [tradename] catalog and [tradename] catalog and we have logic on top of that to aggregate those together to merge them. But what do we do actually? We take some data, we change how it's represented, we store it here, and then we present it to the client in the way they want it represented. And then they display it to the user in the way that the user can understand. And then the user ingests it, and the user buys something, and we make money. That's what we do. We manipulate data.

Participants use many different types of data in their daily work, including energy and emission data, data related to machine components or processes, cost data, chemical, physical and mechanical data for various materials, wage and benefit data, product data, safety data, infrastructure data such as the location of water mains, sewers, or electrical components, driving records, credit scores, educational levels, genomic data, and bioassay data. Chris commented, "You're pulling in a variety of different sources of information from clinical protocols, lab manuals, talking to the pharmacokinetics (PK) scientists and how much PK sampling they're going to need to get their endpoint. So that was big, you know, pulling in multiple sources and coming to a conclusion."

Participants obtained data through both internal sources such as laboratory testing, reading internal reports, and talking with subject matter experts, and external sources from government websites, clients, trade shows, online data mining, town officials, vendors, and literature reviews. Travis remarked,

> I'm locating and compiling lots of data for estimating the total cost of building and maintaining a new search and rescue airplane for the Coast Guard. Primary data sources include talking to people, reading reports and interviewing subject matter experts." Secondary sources included Internet searches, internal Coast Guard reports, official reports from the Government Accountability Office (GAO) and existing financials systems to extrapolate cost.

However, many participants discussed the difficulty in obtaining data, finding the right kind of data, or finding trusted sources of data. Others mentioned the importance of being able to decide what was the most relevant data or knowing when to "draw the line" on collecting information. Ian noted, "I had to be able to weigh things differently. How do I weigh something that a sales person was telling me versus what I found in my own research, versus what I might have called someone else in the company and talked to them? How do I consider all these and then give them the appropriate amount of weight." Similarly, Kevin remarked, "Before I started fulltime, I really hadn't had any cases where the information you're getting isn't necessarily reliable, and having to figure out what someone is trying to say or what something means. And they're saying one thing, but it seems like they mean another thing."

a. Learning to Locate, Organize and Analyze Data from Multiple Sources

Participants recalled learning how to locate, organize and analyze data through high school and college lab experiments, senior design projects, M5, research, iCons, professional societies, relevant books, internships and jobs. Several participants identified increased problem complexity and building experience over time as critical factors to being able to locate, organize and analyze data. Caitlin noted that most school projects are very prescribed, saying, "They tell you what's supposed to happen. You don't get really ambiguous problems until the job." Dan commented, "This is the challenge of real life—the level of complexity. In class, you get data from just one source, one machine. None of the projects compare with what I'm doing at work." He went on to say, "In school, you learn how to analyze and organize data within single sources, maybe two at most. But this is the challenge of real life where you're trying to extend the number to five or six, so it's the application, I guess. You're using your ability, you're stretching it."

However, these participants believed that they built confidence over time, and often with the help of a strong supervisor or mentor. Several participants pointed specifically to influential mentors, supervisors, or colleagues who guided them in process. Caroline commented, "My mentor described the process of locating, organizing and analyzing the data. She was an excellent mentor, and I think that's really important—having good mentors. You know, I was helping her and she trained me because she had clinical responsibilities to see patients." Greg noted, "When developing a complex system, the process is very collaborative and there are different players all providing inputs and ideas. If the contributors are not on the same page, then nothing cohesive is accomplished. Everyone needs to be able to see the big picture and make decisions, and there needs to be leaders who can put the pieces together."

5. Learning Outcomes g, h: Knowledge of contemporary issues and new developments in science and technology, and the ability to use the techniques, skills, and modern technological tools necessary for solving complex problems.

Participants described their knowledge of contemporary issues and new developments in science and technology as very closely tied with their ability to use the techniques, skills, and modern technological tools necessary to solve complex problems. For participants working in the biotech or the computer industry, or in the research and development divisions of commercial products companies, an understanding of contemporary issues was viewed as critical in order to stay at the forefront of their industry. Greg explained, "Understanding the playing field of the industry/competition is really important in my current industry of consumer electronics. You need to know what is going on and what others are doing to stay relevant and innovate." Working in the biotech sector, Chris noted:

> Knowing where the market's going and where the interest is. And there's an economic facet to that and a competitive facet to that—meaning, competitive intelligence. How many other companies are trying to attack this target? If we know that a certain marker is expressed on this tumor, how many other companies are going there? Where are they in their development scheme versus our scheme? So that's the competitive side. And there's also the economic side of what other technologies are attacking this. Where is most of the funding going to? Investors might like the cutting edge immunology therapies. You might see a lot less funding in conventional types of therapies, so we have to be aware of those types of aspects.

For participants in these fields, the use of new techniques and modern tools enabled them to stay at the leading edge of these competitive markets. Participants in the biotech industry pointed to technologies such as 3D printing, organ on a chip, and biodots as important scientific advances that they are using or exploring. Caroline noted, “You want to keep your finger on the pulse of what’s going on because all of these new developments that are making the news right now, like CRISPR CAS9. These are going to be things that will become the research tools of our future.” Greg described the importance of keeping current in the rapidly changing computer industry. He noted,

> Having an awareness of languages used for app development--being familiar with the android and IOS framework and languages like SWIFT and Java, and knowing what’s available for back-end things and understanding what matches in the big system pictures each type of thing should reside, and understanding the strengths and weaknesses of the different layers…Technology is changing so much, especially with the internet and cloud computing and platforms like that. Not using it would be a mistake.

Participants working in more established industries such as manufacturing of mechanical components, insurance, or in government or municipal jobs described the necessity of understanding contemporary issues and new developments in science and technology from the point of view of being able to improve current products or make products more user-friendly in order to stay competitive. Kevin commented, “I think there’s a lot of push toward ease of use and consume-ability of things, in being on top of what those changes are. These are important to the success of the product overall.” Others expressed the need to understand new developments and to be able to use new tools and technologies as a way to increase productivity or improve efficiency. Working in the manufacturing industry, Marco described his company’s acquisition of new tools as follows:

> We just got a 3D printer…in the near future we’re thinking of actually getting a 3D printer that prints with metal. Right now we’re doing plastic, but that will help us to justify the metal printer. Also, our company tries to grow and tries to get new machinery. We’ve currently got a laser cutter. We also have expanded and got a new heat treat unit with new machines. As the company is growing, we tend to get new and

> better machines. We have a whole section of presses, and currently we are getting a six hundred ton press. So we try to be, like you said, in the verge of technology.

Some participants talked about using “new to us” technologies including Excel spreadsheets, improved Power Point presentations, and the camera feature on phones when documenting problems in the field. Others discussed new technologies relevant to their particular field of work. Working in project management, Tim described a new cured-in-place pipe liner technology for water mains. Ashley pointed to technologies that are changing the insurance landscape such as Uber, Airbnb and self-driving cars.

Participants in the study also referred to contemporary issues in energy and cybersecurity that, while not necessarily the key focus of their industry, were important, higher level considerations for their companies. Participants mentioned the need for more sustainable sources of energy, pointing to their use of technologies such as Bluetooth Low Energy (BLE), or creating an alternative battery for one of their products. Others pointed to the pervasive problem of cybersecurity including phishing schemes that extract confidential or proprietary information. Megan noted, “We have integrated new systems that are more secure. Like email—we have a place where people can upload files securely after logging in rather than just emailing a file. So, that wasn’t, you know, when we started collecting data, that wasn’t there—so just concerns with data security.”

While some participants explained that key decisions involving these larger contemporary issues are filtered at the “higher level”, others described the necessity of keeping abreast of tax law implications, trade agreements, and regulatory guidelines both domestic and abroad. Marco described a problem with the steel supply chain in the manufacturing industry. He noted,

> We try to buy locally, here in the U.S.A., but most of [the steel] we buy from Japan. That takes about six to eight weeks just to ship it over, and then customs—that’s another two weeks. We’re always having issues with shipping. I think last year we got hit with a

> strike in California in the ports, so that definitely also affected us. And, plus, one major one was from one of our steel mills here in the U.S.A. They just shut. Completely closed the whole company on us. One of the steel mills they just closed overnight, and then we were just stuck mid-air, like, 'where are we gonna get our steel?'

a. Learning Contemporary Issues, Modern Techniques and Tools

Having knowledge of contemporary issues and new developments in science and technology, and being able to use the techniques, skills, and modern technological tools necessary for solving complex problems was learned almost exclusively on the job or as a result of individual participant's personal interest and curiosity. Only two participants credited learning about contemporary issues in the college environment. Kevin noted, "There was one user experience class at UMass, but I didn't take it." Dan explained, "Especially the things I do—I don't think there aren't a lot of labs in the U.S. that do it in the first place. It's special, kind of like a specialized area. At school, you're limited to what you have access to." Paul, however, pointed to his experience participating in the Hack-a-thon and to a peer mentor in M5 who taught a non-credit "Ruby on Rails" course. He recalled, "Those were, to me, new technologies, and new things that I didn't know that came of value in my career. And this was all through some guy who happened to teach himself and share the information."

Those participants who described their knowledge of contemporary issues and their use of modern tools as being self-directed pointed to reading books and journals on specific topics, listening to news, using technical online resources or just "playing on my own" with new technologies. For these participants, a natural curiosity in cutting edge technology and having an understanding of the social and economic factors affecting the world drove their ability to explore and learn these new developments in science. Travis commented,

> I can tell you that I learned a lot from sources like NPR about how manufacturing in America is so down. It happened to be that they had this huge month-long series on it as I was working [at a manufacturing facility], and I thought it was so interesting because you get to learn *why* it's so hard to produce in a big sense. We were a specialized job

> shop for a niche market—aerospace components for like three companies. And I heard from the guys how many jobs we lost. Smith and Wesson was a huge customer and we lost them five years before they hired me, and they were a customer for 15 years.

Other participants noted that critical factors for staying current and learning new technologies included having the personal desire to be on the cutting edge of knowledge, actively seeking out new technologies, and having a passion and willingness to "dive deep" in understanding technical problems. Others pointed to having access to certain types of equipment and software packages and the use of open source software.

Most participants indicated that they gained knowledge of contemporary issues and learned new scientific technologies on the job. These participants pointed to vendor "lunch and learns," peer presentations, mentors, supervisors, professional conferences, industry association meetings and publications, and internal company websites dedicated to contemporary issues relevant to their industry. Kevin noted, "[Our company] does a great job of sending scientists, depending on what level, to 1-5 conferences a year. So that's where a lot of people stay cutting edge and see what competitors are doing in the space, where the industry is trending toward." Caroline, working in a start-up incubator space explained,

> They have lots of 'lunch and learns.' They have many different seminars that they host here and most of them are free—so it's amazing! This is a great space for doing that. And not only that, but just having exposure to all these companies. Like, companies will say, 'Hey, what you're doing sounds like something we could use. Do you think we could collaborate?' And we have done that—our company has collaborated with a few other companies here.

These participants believed that the commitment from the company to educate employees was a critical factor for keeping abreast of contemporary issues and new technologies in their field. This commitment included actively encouraging collaboration, including allocating work-time for informal communication, paying for employees to attend professional conferences, and incentivizing good ideas or innovations.

6. Learning Outcome i: Recognition of the Need for and an Ability to Engage in Life-long Learning

Participants in the study expressed the need for and the ability to engage in life-long learning from two perspectives: externally-motivated factors and internally-motivated factors. Externally-motivated factors centered on job security and job mobility. Several participants discussed the notion that in a rapidly changing industry, they needed to "keep up" with new information, new tools, and languages in order to stay competitive in the industry.

Kevin noted,

> If you don't continue to learn, you're going to find yourself out of a job…I mean, God forbid you ever get laid off, finding a new job if you said you work on this decade old technology that no one uses anymore. If you're lucky and you can find someone who uses that, good for you. But as a general rule, it's important to stay up to date with the current technologies even if it's not something that's going to stay around forever. People love the buzz words. Even at my company, people throw around like, 'oh, Node JS.' All this fancy new—it's not that useful, but people get excited about it. People and their buzzwords—I'm very cynical.

Similarly, Dan noted,

> Because I'm in the R & D center, we're constantly looking for innovation in order to stay competitive. We have to keep trying things—be updated on current progress in our field. We are continuously learning because we can't settle for pre-existing product lines. There will always be competition and better products eventually. So, in order to stay ahead and be competitive, you have to keep learning.

Other participants connected continuous learning with starting a new position that had a steep learning curve, or learning how to operate new equipment or use a new programming language. Brian remarked, "This position is all about learning. I feel like I've learned more in the last few months than I have learned in the last year of college. It just constantly—there's this new thing you need to solve and to solve this new thing you need to learn something new. It's kind of what, what it means is that you can't solve today's problems with yesterday's tools. Like, you have to keep finding new methods." Others described moving into a new direction and needing to learn skills associated with the position. Megan noted, "I am interested in going to work on the statistical side of the program. But, I need more background in statistics to do so. So, I'm going back to school for my master's in statistics. I'm in my second class, so I'm continuing my learning so I can move within the company." Kevin, who was moving into more of a business role, remarked,

> I'm starting my MBA in the fall. Constantly learning finance and also outside of the realm of biochemistry and the biotech and pharma space. Look where everything else is going. What is the trend in society? You see everything moving toward electronics, personal devices. People have to think, 'How is my job going to change down the road? Does this mean it's going to be computer intensive? Should I take a computer scripting course?' That's ultimately what drives me. I always try to think ten steps ahead. Whether it helps me in my job, or just gives me a sense of security down the road.

Several participants acknowledged that the main driver for continuous learning was the benefit of advancing their jobs and especially the financial rewards associated with "moving up" in the company. Greg explained, "For me it's personal—I want to constantly be learning because I enjoy it, but also, how can I advance my career—that's the driver. I want to continue to be able to support my family. I know that's a cliché, but I want to be able to continue advancing my career so that I can successfully support my family and live the life that I ultimately want to live." Similarly, Megan commented, "I guess opportunity—what do they say—it's a combination of timing, and luck, and preparedness, or something. So, I'm just doing my part so that when the time comes, I'm prepared to move on." Ian noted,

> If I want to have a position of strength in the company, a position of responsibility, I have to be valuable to that company—that's the only way to get there. And if I want to be valuable, I need to have valuable skills. So, I need to always be pushing that envelope. I need to be looking for ways to learn and ways to expand and challenge myself. Because if I'm not, then I'm sort of spinning my wheels and just sort of complacent, and I won't ever get there.

<u>a. Learning Life-long Learning</u>

Participants discussed formal ways of engaging in life-long learning through various types of continuing education opportunities. These opportunities included courses taught within the company on specific subject areas, formal master degree programs such as MBA or MS in Engineering Management, or passing exams for certification such as the P.E. or actuarial exams. For participants interested in engaging in these formal avenues of learning, critical factors included tuition reimbursement from their employer, accessible class times, supervisor approval and encouragement, and financial incentives. Caroline noted, “I don’t think many people actually want to quit learning. I don’t think I know any. No, I think access might be an issue. Like, life is hectic and busy. People who are working full time, and if they have children or other family responsibilities, it would be easy to put [education] on the back burner. So, I think access is important.”

In addition to the need for continuous learning in the workplace, many participants discussed their internal motivations for learning. Several noted that, “it’s just part of my personality,” “I’m curious,” or “I just love learning.” Dan remarked, “For me, I would want to keep learning because I would hate to be just living in this frame of mind, in this box. I want to be able to expand my horizon because life is full of exciting stuff. I want to know what’s out there. That curiosity is going to motivate me to keep learning. Otherwise, I think life would be very boring.” Similarly, Kevin recalled,

> I’ve always had a curiosity to understand how things work. My mind is just an information sponge. If you look at the home movies from when I was little, we’d have the birthday parties and I’d walk up to the camcorder and try to figure out how it works. And they were like, ‘Kevin, get away from that, it’s expensive!’ And I’d keep coming back. If something breaks, I take it apart to figure out how it works and see if I can fix it—that sort of thing. It’s how my mind works. I’ve always been drawn to learning new things and trying to figure out how things work and that kind of thing.

Participants credited being internally motivated to learn from many different sources including parents, scouts, M5, high school and college projects, internships, conferences, and in their job. Many participants pointed to their parents as a driving force in continually developing a love of learning through encouraging curiosity, sharing current events and news, having conversations about self-improvement, exposing them to a wide range of people and events, and allowing them to try many different extracurricular activities. Caitlin recalled, "I learned from my family. My parents encouraged me to fulfill my curiosity. They kept up with the news and enjoyed sharing their knowledge."

b. Critical Factors in Recognizing the Need for and Ability to Engage in Life-long Learning

Participants also detailed a wide range of factors that they believed to be critical to engaging in life-long learning. Several participants expressed the importance of having people in their lives that encouraged learning and curiosity and in putting themselves in challenging situations that require learning or opportunities to grow. Travis noted, "I mean if it got squashed, that would be terrible. I was always encouraged, from family to school to teachers and peers. I mean, that's so huge—just encouraged to learn more." Brian recalled, "If I never tried to do something like programming or research, like any of those things, I would have never found them interesting, so I wouldn't have gotten to do it. So every one of my internships, every one of my projects—I think projects where I got creative freedom—or in any, all of my internships and my research here at UMass, all gave me an opportunity to try and do something."

Others pointed to having projects that had "real life" or meaningful outcomes and having the personal freedom to define how to approach problems in a creative way. Reflecting back on her experiences in M5, Caitlin noted,

> I didn't always like school, so I'm trying to back up to when that changed. It's probably more related to when I started connecting with real life outcomes, whether that was on the job, or, I think a big part of it was also M5 because that was really a showcase of the difference between in-class learning and out-of-class learning…That learning didn't end in the classroom, and that people actually enjoyed it outside of the classroom.

Paul remarked, "A lot of the whole open-ended component often means that I can sort of decide how well I want to do something, or how much I want to put into it. And if I don't feel interested to promote some type of life-long learning and learning on my own, work just gets way less interesting. And if it's less interesting, I do worse work."

While most participants gave positive responses to experiencing life-long learning, either from a workplace-driven, or personal-driven perspective, three participants described barriers to being able to engage in life-long learning. Mike explained that, for him, the desire to continually learn doesn't come naturally. He commented, "I think it's something that you actively push for. It doesn't naturally happen. It's really easy to be lazy, especially given the right parameters. Like, if I was given a bunch of money and a beautiful island, my life-long learning would slowly taper off, I'm sure." Two participants explained that, while they would like to learn more, it wasn't encouraged at their jobs. Tim remarked,

> I feel the need to constantly learn, personally, but I'm not constantly learning. I wish I was. I brought it up before with my boss. I feel like I'm not learning anything new and I want to challenge myself somehow and haven't really gotten anything out of that. The company offers these, like, you know, 'Design a Pump Station 101' sort of things, which are interesting. But it's just listening to someone give a presentation—it's not really doing anything with it.

Both of these participants worked at companies that had a "billable hours" model. Travis commented,

> At a machine shop, every minute is billable--every minute you could be producing a thing that makes you money. So every time that was sitting down, I had to be working, and if I really couldn't work anymore, I should get up and go run a machine. So I would run a machine and run parts. And so, I did not feel like learning was valued there. I knew the value in my head, but I didn't feel like I was allowed to do it.

C. Conclusion

The stories that these participants shared represents approximately 20 hours of in-depth interviews. All nine of these learning outcomes are necessities for the STEM professionals in this study, and these stories emerged from their daily experiences. Being able to reflect on how they learned these competencies and what the critical factors were in learning, provided the participants the opportunity to consider their own experience and share their knowledge with others.

As a phenomenographic study, participants were purposely sampled in a manner that would explicate the variations on how STEM professionals experience the nine stated learning outcomes across a broad range of STEM-related industries including biotech, computer/electronics, manufacturing, R & D, project management, insurance, and government. Participants held degrees from a range of STEM majors, worked in a wide variety of jobs, had participated in a range of problem-based experiences as students, and represented demographic diversity. Their responses to the interview questions reflected both common and unique experiences that help to shed light on the range of early career STEM experiences. An analysis of these responses will shed further light on the different ways that early career STEM professionals experience and continue to learn the competencies necessary for STEM practice.

CHAPTER 5

DISCUSSION, IMPLICATIONS AND CONCLUSIONS

A. Introduction

The initial motivation for conducting this study was to understand if problem-based learning could fill the gaps in STEM education in the same way that employers believe internships do. Results of the study suggest that for some of the learning outcomes, problem-based learning can be a proxy for internships. For others, certain types of problem based learning seem to be effective, while others do not. Finally, for some learning outcomes, problem based learning was not effective. The major results of the research consist of 1) rich descriptions of the variety of ways the learning outcomes are experienced in the workplace, 2) an identification of the environments where the learning took place, and 3) an understanding of how the outcomes were achieved, that is, the mechanism by which learning occurred.

The variations described by participants provide new and important insights into the ways that STEM professionals actually experience the skills and competencies they need to be successful engineers and scientists across nine industry types. Together, these descriptions reveal the range of ways that the learning outcomes are experienced, which are presented in detail in Chapter 4. Analysis of the range creates a landscape view of the way that STEM professionals learn those competencies.

Where does the learning take place? For the technical learning outcomes, results of the study indicate that a wide range of relevant, hands-on experiences can improve a student's ability to use math, science and engineering principles, problem-solve, and locate, organize, and analyze data from multiple sources. In addition to internships, these experiences can take a variety of forms, including problem-based learning courses, makerspaces, research projects, design projects, and student clubs. Additionally, many participants credited their understanding of math concepts to their middle and high school educations, pointing to the important role that a robust K-12 education plays in providing a strong foundation for STEM professionals. However, with the exception of the makerspace and a student-run hack-a-thon where innovation was incentivized, participants only gained an understanding of contemporary issues, new developments in science and technology, and the use of modern technological tools in the workplace.

For the non-technical learning outcomes, participants in the study believed they gained an understanding of professional and ethical responsibility and the ability to engage in lifelong learning mainly through their internships or jobs, or from background, contextual influences such as parents, siblings, individual teachers or mentors, sports teams, or scouts, but only minimally through problem-based learning experiences. Those who had participated in iCons described the program as an ideal environment for developing technical writing and presentation skills. Specific instruction in making a good slide or a good figure for a presentation, using data to make a persuasive argument, and having multiple opportunities to practice technical writing and giving presentations helped participants in the iCons program gain self-efficacy in communicating technical information. They identified helpful, consistent feedback from faculty and peers as critical to learning these skills. Those who participated in self-directed environments such as M5 or student clubs identified informal collaboration with peers as useful in developing verbal communication skills. Many of the participates, however, struggled with communication skills, especially as they related to teamwork. Teamwork was identified as the most challenge skill to develop, and many participants noted that even in the workplace, they continue to struggle with developing this important skill. Most participants recalled participating on teams throughout their college years, however, they stressed that being on a team did not mean that they learned critical teamwork skills such as conflict resolution, how to divide tasks, and negotiation.

Analysis of the data resulted in a three phase model of learning in which students move from exploration to mastery, and then to integration. Self-efficacy builds over time when students are learning effectively, and as it does so outcome expectations should also change. Early in the learning process, students need the opportunity to freely explore and observe others without fear of negative consequences. In the middle of the process, students need consistent feedback and the ability to retry as many times as necessary after failure, until mastery is achieved. Late in the learning process, students need to work on complex, authentic problems with real consequences. Results of the study suggest that learning environment, type of problem and input from others are all key influences in the learning process.

B. Analysis of Learning Outcomes

In answering the research questions: "How do career STEM professionals gain the competencies needed for STEM practice" and "What do these career STEM professionals perceive to be the critical factors that contributed to their ability to develop the competencies necessary for STEM practice", in-depth interviews of participants provided important insights into the factors that contributed to learning both technical and professional skills. For the analysis, I grouped the technical and non-technical learning outcomes separately. Technical learning outcomes included the use of math, science and engineering principles, problem-solving skills, the ability to locate, organize and analyze data from multiple sources, knowledge of contemporary issues and new developments in science and technology and the use of modern technological tools. The non-technical learning outcomes, or professional competencies, consisted of teamwork and communication skills, understanding of professional and ethical responsibility, and recognition of the need for life-long learning.

1. Technical Learning Outcomes

a. Applying Math, Science and Engineering Principles and Problem-solving Skills

Results from the study suggest that learning the foundational math, science, and engineering principles needed for professional STEM practice is a continuous process that begins in middle and high school and increases in complexity throughout college and on the job. Similarly, the ability to solve complex problems is learned over time with foundational concepts learned in the academic environment and industry-specific concepts and skills learned on the job or in internships. Although the use of math, science, and engineering principles varies greatly by industry, participants expressed the need to combine foundational math and science knowledge with business knowledge in making products or processes more efficient and to stay competitive in the market. Results of the study suggest that three critical factors contribute to this learning process: type of environment, type of problem and feedback from others.

i. Type of Environment

In the early phase of learning technical concepts and problem-solving, participants pointed to environments that stimulate curiosity and allow a person to try new things and make mistakes as particularly useful. Results of the study suggest that these environments can include makerspaces, the laboratory, student clubs, and academic projects within the structure of a class. Whatever the environment, the student needs to be able to explore new concepts, equipment, software, or materials without worrying about negative outcomes or external pressures. These environments foster self-directed learning and provide students with the opportunity to build self-efficacy through exploration and “what if” thinking. Several participants in the study pointed specifically to the makerspace, M5, as an ideal environment for this type of creative exploration.

As their knowledge and skills grow, students need opportunities to master concepts. Participants described the benefit of repetition and the ability to frequently practice skills and behaviors. Weibell (2011) noted that, "the role of repetition … is in the similarities found when relating new experiences to previous experiences" (Chapter 4, para. 21)). Environments that enable student to learn from mistakes and repeat work provide a proving-ground for reflection and testing. Finally, as mastery is accomplished, participants in the study noted that creativity in applying math, science and engineering principles was critical to innovation and pushing beyond the limits of current technologies. Environments that provide access to modern technology such as equipment or software and encourage discussion of current events and discoveries in science foster creativity and out-of-the-box thinking.

ii. Type of Problem

Participants in the study noted that they learn best within the context of a meaningful problem. Results of the study suggest that problems can be introduced in a variety of settings including makerspaces, research labs, student society or club projects, within the structure of a course, as well as in internships or on the job. In the early phases of learning, problems were most often generated from student-centered projects that were interesting, engaging, and required creativity to solve, such as the robotic project in M5. More advanced problems, such as those in senior-level design classes and the iCons program were ambiguous and required multiple data sources and perspectives to solve. Consistent with the literature, participants in the study described learning best when faced with problems that were open-ended and provided opportunities to examine evidence and collaborate between multiple viewpoints

(Walker & Leary, 2009) such as decision-making problems, trouble-shooting problems, optimization problems, and design problems. Participants in the study also remarked that students need to feel that their contribution matters and they have ownership of the problem. They noted that internships are especially effective in providing these types of relevant, meaningful problems. Finally, the study suggests that problems should increase in complexity over time and include a reflective component that gives students the opportunity to think about the big picture and the various factors that contribute to the problem.

iii. Feedback from Others

Participants in the study identified mentors, supervisors, and colleagues as key figures in learning technical and problem-solving skills. Early in the learning process, participants benefited from vicarious learning by watching mentors, teachers or supervisors complete specific tasks, use technical equipment, give presentations, or solve a challenging technical problem. Participants noted that good mentors strike a balance between letting the student or early career professional try to solve the problem on his/her own and providing guidance and feedback. Results of the study support previous findings that feedback from influential people is an important factor in developing deeper conceptual understanding (Bangert-Drowns, Kulick, Kulick, & Morgan, 1991) and improving motivation and self-esteem (Dempsey, Driscoll & Litchfield, 1993). In a study of 76 university students, Wang and Wu (2008) reported that receiving detailed feedback promoted self-efficacy in students, and receiving knowledge of correct responses improved student performance (p. 1589).

While teamwork was a challenge in the academic environment, many participants described the benefits of collaborating with other professionals in internships or on the job.

Participants noted that they were better able to solve technical problems by sharing information and discussing new ideas and perspectives with other STEM professionals.

b. Learning to Locate, Organize and Analyze Data from Multiple Sources

Results of the study indicate that locating, organizing and analyzing data from multiple sources is a key component of early career STEM professionals' work, across every industry type. Participants spoke extensively about the daily need to use data from multiple sources in order to accomplish their job or when making important decisions. Some participants in the study described learning how to locate, organize and analyze data over time, from simple data collection in high school to more sophisticated methods in college and the workplace. However, several noted that they felt minimally prepared in this skill.

Those participants who recalled learning how to locate and analyze data while in school pointed to either problem-based learning environments such as iCons or senior design courses, or out-of-classroom activities such as research projects, or student societies. In particular, those who participated in the iCons program reported confidence in their ability to locate, organize, and analyze data from multiple sources and to use the results of the analysis in decision-making. These results are consistent with previous studies on the benefits of problem-based learning in regards to improved self-directed learning, the ability to gather information, and problem-solving skills (Schmidt, Vermeulen & van der Molen, 2006).

Other participants described learning how to locate and analyze data in their internship or on the job, and indicated that colleagues, mentors and supervisors played an important role by contributing ideas and providing input. These participants expressed the need to learn a variety of data collection methods that include primary, secondary and tertiary sources, and to build a base of organizational and analytical tools that could be used as problems increased in complexity.

c. Learning Contemporary Issues in Science and Technology and How to Use Modern Technological Tools for Solving Complex Problems

Results of the study suggest that, unlike the other technical competencies, gaining knowledge of contemporary issues and new developments in science and technology and the ability to use the techniques, skills, and modern technological tools necessary for solving complex problems is *not* learned in the classroom. The only academic environments in which participants learned these skills were the makerspace and a student-run “hackathon”. These venues involve peer and professional mentoring, collaboration, inspiration for new ideas, and incentivizing innovation.

Most early career STEM professionals keep abreast of contemporary issues and use modern technology on the job, through professional conferences, industry association meetings, or technical publications. Some pointed to other company resources such as dedicated websites, “lunch and learns”, or peer or supervisor presentations. Critical factors to professional’s ability to “keep current” include access to new technologies such as equipment or software, support from the company for conference attendance, continuing education, and incentivizing innovation.

2. Non-technical Learning Outcomes

Consistent with the literature, most of the participants in the study believed that they were proficient in technical knowledge but struggled with communication skills, working in cross-functional teams, and understanding the organizational and cultural contexts of engineering practice (Meier, et al., 1999; Reich, 1993; Sageev & Romanowski, 2001; Lattuca, Strauss & Volkwein, 2006).

a. Communication and Teamwork

Communication and teamwork skills were recognized by participants as being tremendously important components of their daily work, and yet the most challenging. One notable feature of both communication and teamwork was the broad scope that these skills take in the STEM fields. Communication skills included sharing or clarifying technical and non-technical information both informally and through formal presentations, pitching ideas, giving and getting feedback, training, identifying and conveying risks and time constraints for projects, conflict resolution, and maintaining lab or field notes. Participants noted that these skills were used across a range of settings such as one-on-one conversations, small group meetings, phone calls or email, technical or business reports, video conferencing, or large presentations. Teams included members from a range of backgrounds, cultures, educational levels, business levels, ages, disciplines and languages.

This broad range of uses led to a variety of challenges for participants in the study. A chief communication challenge was in understanding the different priorities of those on the team and learning how to communicate both effectively and efficiently depending on the situation. This challenge also included understanding the time constraints, power structures, and appropriate level of detail to use for presentations or technical reports. Many identified the need to develop better writing, presenting, and conflict resolution skills.

In learning communication and teamwork skills, participants pointed to parents, teachers, extracurricular activities such as scouts, band, and sports teams, college design teams or other competitions, the iCons program, student professional societies, part-time jobs, internships and, eventually, their professional workplace. Learning good communication often started with watching others and then mimicking their behavior. Critical factors that contribute to learning communication and teamwork skills include having a manager, supervisor, or teacher who models good teamwork skills, valuing the benefit of multiple perspectives in solving complex problems, having shared goals, understanding power structures within the organization and within the team, sharing information, and being able to practice skills in a low-stakes environment where they can learn from mistakes. Several participants pointed to the iCons program as especially effective at teaching communication skills within an academic environment. Specifically instructing students on what makes a good slide or a good figure in a presentation, how to use data to persuade others, and giving feedback on technical writing helped students learn good communication skills. Missing from the learning process in both academia and industry, however, is instruction in conflict resolution, negotiation, expressing ideas or feelings in a non-threatening way, active listening, strategies for dividing tasks and understanding different types of communication styles.

b. Ethical and Professional Behavior

Participants in the study understood ethics and professional behavior in different ways. Participants who described ethical and professional behavior as having "life or death" consequences worked in high stakes jobs such as airplane manufacturing, drug manufacturing, or public works projects. Some participants described ethical behavior as safe-guarding information: either trade secrets or client confidentiality. Others pointed to providing accurate data to be used in decision-making, or considering how their individual work affected other's safety or time. Still others commented on ethical behavior as being mindful of how their product might be used, operating in a sustainable manner, or spending their workday being productive.

Overall, participants were thoughtful and reflective in describing how ethical and professional behavior informed their work. They recognized the important role that ethics plays in their day-to-day practice as well as the long term consequences of ethical decision-making. Many participants credited learning ethics from their parents or church, or though participation in scouts. Three participants identified their junior writing professor as introducing them to a new way of thinking about professional ethics that profoundly influenced their way of thinking about ethical behavior.

c. Lifelong Learning

Participants in the study clearly understand the need for life-long learning. As technology changes, early career STEM professionals described needing to remain current in order to progress in their careers. In addition to this external motivation, participants in the study expressed a personal desire to continue to learn and to challenge themselves to grow. The chief skills and dispositions needed for life-long learning included curiosity, initiative and reflection. Participants identified critical factors to life-long learning as: encouragement of curiosity, opportunities to explore new things or new ideas, having meaningful projects and creative freedom in how to approach them, and exposure to a wide range of people, ideas and activities.

C. Development of Learning Model

I used two foundational learning theories to frame the research. While useful, these theories did not completely explain how participants in the study learned the key skills and competencies needed for their careers. Therefore, analysis of the data resulted in the formation of a new multi-phase model that explains how exploration, mastery and integration constitute three distinct phases of learning for the STEM professionals in the study. Mjoset (Research Council of Norway, 2011) identifies contextualized theories as “the most promising and adequate for the educational sciences, and especially the contextualized explanation view of theory" (p. 6). In the current study, gaining a contextualized perspective of how STEM professionals learned the skills and competencies needed for practice, provided the insights into developing a new Social Cognitive Experiential Learning Model.

1. Theoretical Framework

This study was framed by two relevant learning theories: Kolb and Fry's Experiential Learning Theory and Lent, Brown and Hackett's Social Cognitive Career Theory. Experiential Learning Theory suggests that through relevant, hands-on experiences, students gain the confidence and self-directed learning skills that result in improved problem-solving, information gathering, and interpersonal skills. The model describes how concrete experiences, reflection, forming abstract concepts and testing in new situations constitute four distinct stages of learning (Kolb & Fry, 1975).

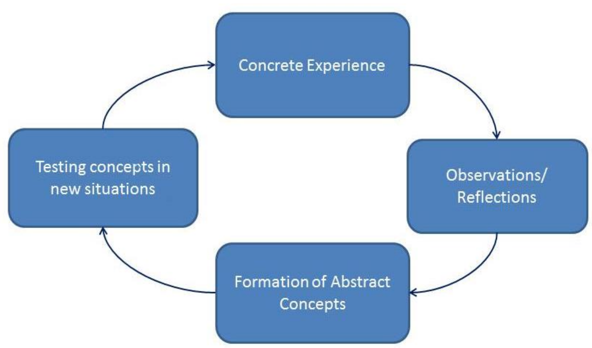

Figure 3: The Experiential Learning Model (Kolb & Fry, 1975)

By applying academic knowledge to relevant problems, experiential learning provides students with the opportunity to build on their conceptual understanding and develop confidence in completing specific tasks. The study did not directly assess the four stages of the Experiential Learning Model. However, the analysis of the interviews confirmed that hands-on experiences result in improved technical and self-directed learning skills as described in the literature.

Lent, Brown and Hackett's Social Cognitive Career Theory (1994) adds to our understanding by considering the role that social constructs play in the learning process. SCCT seeks to explain how interactions with others influence the learning process through observing behavior, gaining feedback from peers or supervisors, introducing new perspectives on a problem, and necessitating communication and teamwork skills. SCCT suggests that while personal characteristics and background experiences contribute to an individual's learning, contextual influences also affect the learning outcomes through the development of an individual's sense of self-efficacy and outcome expectations.

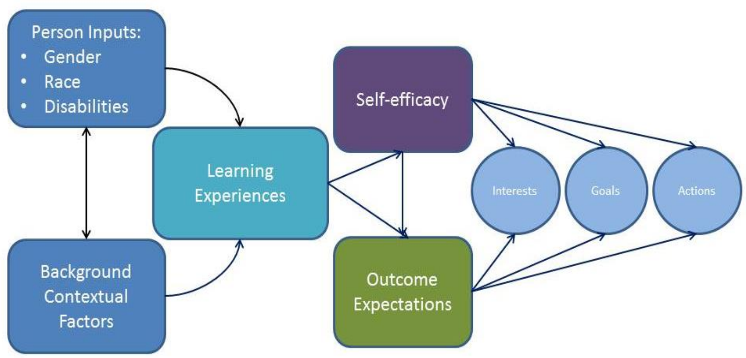

Figure 4: Social Cognitive Career Theory (Lent, et al., 1994)

Analysis of the data suggests that background contextual influences such as parenting style, family size, and type of home environment play an important role in career-related expectations. Furthermore, participants in the study developed self-efficacy both directly through hands-on experiences and vicariously by watching and imitating others and by gaining feedback from peers, teachers and supervisors. Taken together, Experiential Learning Theory and Social Cognitive Career Theory provide the framework for understanding how students transform concrete experiences into a generalized knowledge and how social constructs affect the student's sense of self-efficacy, outcome expectations, and eventual performance.

2. Proposed Social Cognitive Experiential Learning Framework

The results of the study suggest that while Experiential Learning Theory and Social Cognitive Career Theory each provide an important foundation for understanding the mechanism by which students learn, neither is completely sufficient for understanding the pathway by which STEM students achieve desired learning outcomes. The proposed framework expands the Experiential Learning cycle by suggesting that components of Social Cognitive Career Theory (self-efficacy and outcome expectations) are influences in the experiential learning process. Moreover the influence of others, learning environment and type of problem contribute to the development of self-efficacy. The results of this research suggest that early career STEM professionals build self-efficacy over time as outcome expectations change, giving rise to a multi-phase cycle of learning. The framework can be expressed through the following three phases:

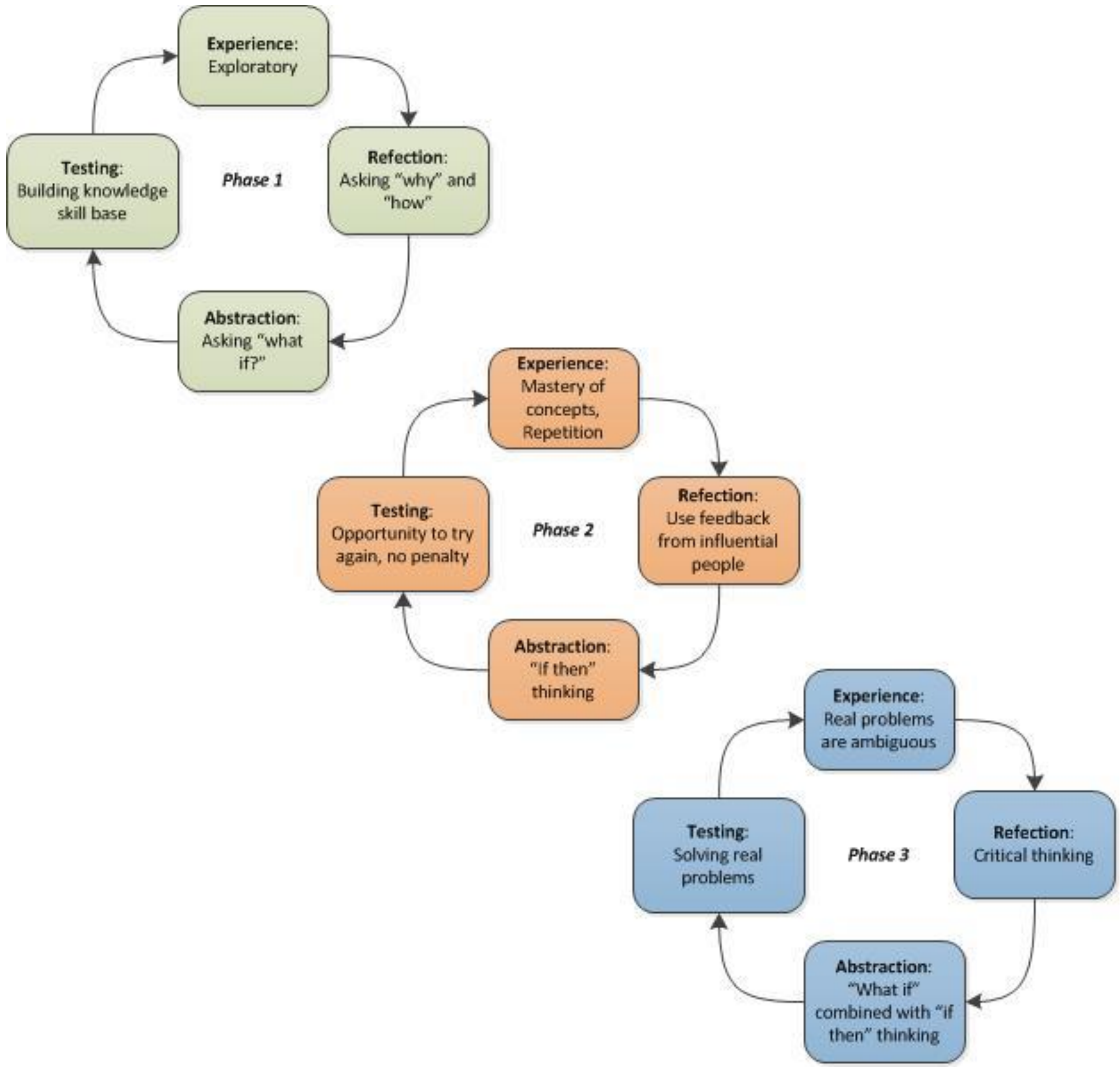

Figure 5: Three-Phase Learning Model

A more detailed description of each of the three phases provides insight into the outcome expectations and critical factors associated with each phase of the framework.

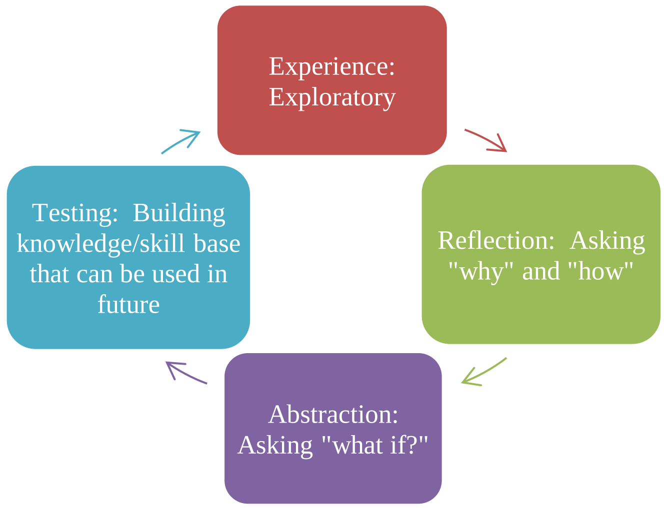

Figure 6: Phase 1 Exploration

Table 3: Phase 1 of Multi-phase Social Cognitive Experiential Learning Theory

Phase 1: Outcome expectations: Explore	**Phase 1: Critical factors**
• All about exploration: no such thing as "failure" • Characterized by "what if" thinking • Act on curiosity/exploration • Build a knowledge-base of possible options and/or tools	• Access to exploratory space and tools • Exposure to a variety of perspectives • Vicarious learning as well as hands-on learning • Stakes are low: no "grades" or negative consequences

Phase 1 is characterized by exploration and the ability to try new things, use new tools, and explore new ideas without fear of failure or negative consequences. As students try new approaches and techniques, they begin to build a base of knowledge that they can draw from in future experiences. Also important in this phase, is the ability to learn from others through watching, mimicking, and then receiving feedback and guidance when they attempt to execute tasks for themselves. The outcome expectation in Phase I is that students will explore multiple avenues for problem-solving, collect and analyze data from multiple sources, and consider multiple perspectives. Self-efficacy grows as students develop knowledge and skills that they can apply to future problems.

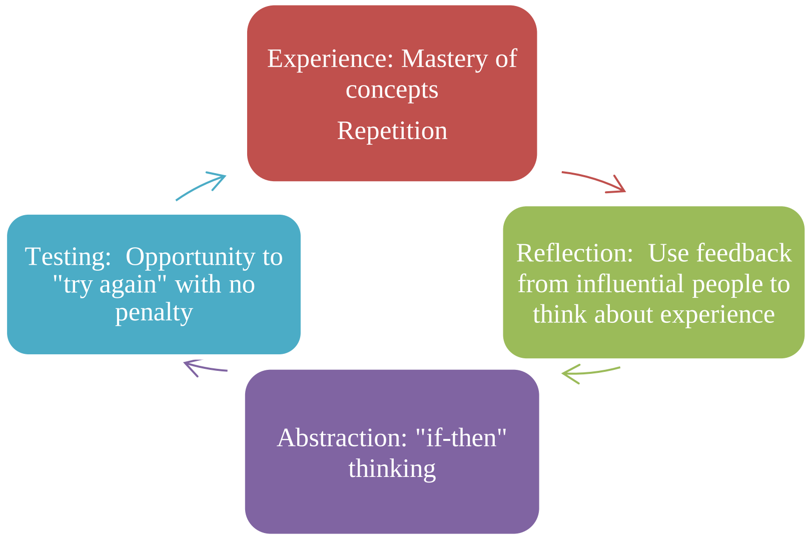

Figure 7: Phase 2 Mastery

Table 4: Phase 2 of Multi-phase Social Cognitive Experiential Learning Theory

Phase 2: Outcome expectations: Mastery	**Phase 2: Critical factors**
• Mastery of concepts/skills • Characterized by "if-then" thinking • Problems are focused at the principles level	• Ability to "re-do" until mastery of concept/skill is achieved • Feedback from influential people • Vicarious learning as well as hands-on learning

Phase 2 is characterized by mastery of skills and concepts. Problems in Phase 2 are focused at the principles level and may require repetition in order to master. Learning environments should include the opportunity to repeat work without penalty until mastery has been achieved. Both vicarious learning and feedback from others are still important components of Phase 2. Students gain self-efficacy through mastery of concepts that they can apply to future problems or situations.

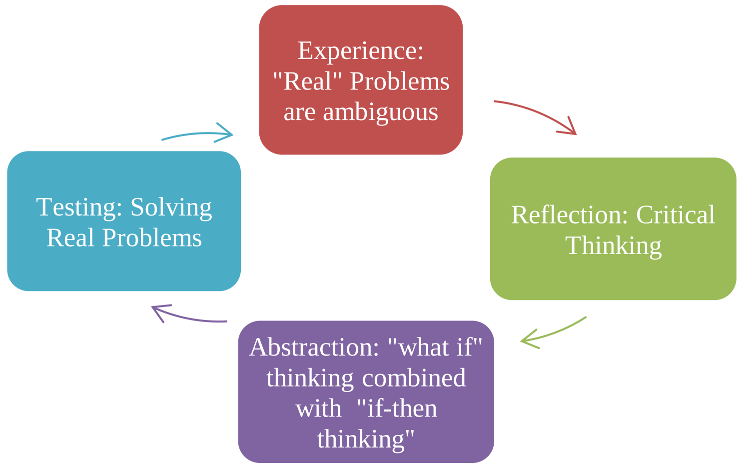

Figure 8: Phase 3 Integration

Table 5: Phase 3 of Multi-phase Social Cognitive Experiential Learning Theory

Phase 3: Outcome expectations: Integrate	**Phase 3: Critical factors**
• Results matter • Problems are complex and require an integration of knowledge, skills and behaviors • Characterized by both "what if" and "if-then" thinking	• Problems are "real" • Stakes are high—sense of "it matters" • Ownership of outcomes ("my name is on this") • Consider a variety of perspectives • Feedback from stakeholders is critical to success

In Phase 3, problems are more ambiguous, open-ended, and "real". Students have ownership of the outcomes and possess a sense that "it matters". Because problems are complex, they require an integration of knowledge, skills and behaviors that have been developed over the past two phases. They must collect, organize and analyze data from multiple sources, but they are able to limit those sources based on the knowledge base that they have developed and the skills that they have mastered. Because problems are multi-faceted, input and feedback from stakeholders is important to success. In order to innovate, students must combine both “if, then” thinking and “what, if” thinking. This combination enables students and early career STEM professionals to bring together knowledge, skills and behaviors in a new way to solve challenging problems.

D. Implications

The study has resulted in several important findings relevant to both academia and the STEM workplace. Responses to the first research question shed important light on the range of ways the STEM learning outcomes are used in the context of actual practice. While the work that accreditation agencies and professional societies have done on identifying the key learning outcomes has been tremendously useful in establishing a common framework for educating STEM students, having an in-depth understanding of the variety of ways those outcomes are experienced in the workplace can help educators to better prepare students for STEM practice. The study provides in-depth explanations as to how both technical and professional competencies are used in the workplace across a broad range of industry types. This information can provide educators insights into the range of ways that a concept or principle is applied, and can serve as an example for instruction or as a problem to be solved in a problem-based learning environment.

Responses to the second and third research questions validate current research on the benefits of experiential learning and provide new insights into the mechanism by which STEM students learn the knowledge, skills and behaviors needed for practice.

1. Conceptual Framework

Learning theories provide a conceptual framework for understanding the learning process. Constructivist theories like Kolb and Fry’s Experiential Learning Theory (1975) emphasize the active engagement of the learner and the process of constructing knowledge from hands-on experiences. Cognitive theories focus on mental processes and posit that learning results from making sense of the relationship between previous knowledge and new knowledge. Lent, Brown and Hackett's Social Cognitive Career Theory (1994) takes into account contextual influences as well as social constructs in understanding how learners learn. The results of the current research provide a unified approach that incorporates both constructivist and cognitive frameworks in STEM learning. The proposed model hypothesizes that learning builds over time as self-efficacy develops through expanded experiences that are influenced by environmental factors and input from others. Other studies have been conducted to explore how environmental and social factors affect the learning process (Frank, Zhao, Penuel, Ellefson & Porter, 2011; Garet, Porter, Desimone, Birman, & Yoon, 2001). For example, Frank et al. (2011) explored how focus on content knowledge, exploration and knowledge transfer impacted elementary school teachers at varying levels of implementation of computer use.

The phenomenographic method also has its own definitive theoretical outlook. It is predicated on the belief that for any given phenomenon, there is not one single, legitimate interpretation, but a wide range of possible interpretations. The learner is an active participant in the process of creating knowledge, because they bring to the process of learning their own distinct questions and make the choice of what to focus on. The phenomena themselves can only be understood in terms of the range of their possible interpretations. They cannot be condensed to reveal a single, inherent truth independent of any observer. This gives phenomenography its necessarily collective approach. It must consider the entire data set as a whole, rather than assessing it as a number of separate individuals.

The results of the study give credence to the idea that the learner plays an active role in creating knowledge, by suggesting that a learner's way of creating knowledge changes as they learn. Taken together, the whole weight of a person's previous experiences frames their way of approaching new experiences, and these experiences in turn affect the way they will frame future events. At the same time, the influence of others can inspire learners to frame their experiences differently, by exposing them to possible interpretations of phenomena which differ from their own. Learning changes the learner, and we need a model that reflects this dynamic.

a. Learning Environments

One of the most frequently repeated themes in the interview data was the importance of having learning environments that foster creativity and promote exploration without fear of negative consequences. Participants found exploratory spaces such as M5 to be particularly stimulating environments because they combine exploration with the opportunity for collaboration and vicarious learning from peers and sometimes professors. When embedded into the academic culture, these spaces provide a broad access for self-directed learning. In addition, if these spaces are adequately equipped with modern tools, equipment and software, STEM students have the opportunity for innovation that comes from integrating curiosity with applied learning.

Within the classroom, environments can also provide opportunities for exploration if learning outcomes are directed at exploring options and understanding multiple perspectives rather than focusing on one correct answer. Communication and teamwork skills can also be fostered within the classroom environment with the inclusion of instruction on specific skills such as presentation, technical writing, conflict resolution, understanding the benefits of multiple perspectives, delegation of tasks, active listening and use of appropriate language.

As learning builds, learning environments should provide opportunities to master concepts through reflection and feedback. In these environments, students are immersed in concepts through repetition of work without penalty. In a 2009 study conducted at Penn State, researchers reported that students who repeatedly solved similar types of problems, whether in an internship, co-op, or in-class assignment, gained confidence in their problem-solving ability.

Results of the study support the notion that learning environments should change over time. In the exploratory phase, these environments should provide access to equipment and tools that stimulate curiosity and provide a variety of hands-on experiences. As students move into the mastery phase of learning, they need opportunities to repeat work and, as Kolb and Fry (1975) suggest, reflect on their experiences, asking what went wrong, how the process could be improved, or what other possibilities could have also solved the problem. As students enter Phase III of the model, environments should include access to new tools and technologies as well as the ability to collect multiple sources of data. Finally, participants recognized the need to develop good working relationships over time by understanding the benefits that different perspectives bring to a team and by focusing on goals and how each team members' efforts will contribute to the solutions. Environments that foster this type of intentional teamwork along with instruction in good teamwork and communication skills provide students the opportunity to practice and improve upon these skills.

b. Relevant Problems

Because STEM professionals must solve a variety of complex problems in the workplace, they need exposure to multifaceted problems that require both analytical and critical thinking skills. Participants from the study noted that authentic problems, or problems that have "real world" applications give students a sense of ownership and pride in solving. Research on the connection between emotion and learning indicates that learning begins with caring about the subject (Immordino-Yang, 2016). Immordino-Yang notes that "It is literally neurobiologically impossible to think deeply about things you don't care about." She goes onto say that "Even in academic subjects that are traditionally considered unemotional, such as physics, engineering or math, deep understanding depends on making emotional connections between concepts" (Immordino-Yang, 2016). Incorporating relevant problems into the curriculum would provide students additional motivation to learn. Moreover, ill-structured problems that can be solved in multiple ways provide students with the opportunity to practice teamwork and communication skills, especially valuing multiple perspectives and practicing making persuasive arguments. Finally, in solving complex, open-ended problems, students have the opportunity to learn how to locate, organize and analyze data from multiple sources. As previous research had indicated, (Barrows, 2002; Hmelo-Silver & Barrows, 2006) problems should be authentic, ill-structured, and self-directed.

Results of the study also suggest that problems should build from simple to more complex over time. Consistent with the research conducted on problem-based learning assessment by Gijbels et al. (2005), problems should begin at the concept level where students identify and explore foundational concepts, followed by problems at the principles level that require students to recognize relationships between concepts. Finally, problems in the application phase require students to integrate knowledge from the concept and principles phase so that they may apply them to a new situation or problem. These phases correspond to the three phases of exploration, mastery and application put forth in the proposed model.

c. Input from Others

Participants in the study repeatedly pointed to input from others as a key factor in learning the competencies needed for STEM practice. The types of interactions included watching and mimicking others, especially experts in a given area, collaborating with colleagues, and receiving feedback from professors or supervisors. Consistent with Social Cognitive Career Theory, results of the study suggest that vicarious learning is an effective method for learning new concepts and skills. Participants noted that observation, imitation and modeling others' behavior resulted in improved confidence in their ability to carry out new tasks and allowed them to reframe previous conceptions about their abilities. Therefore, students need opportunities to observe others who are proficient in a skill and to practice modeling behavior.

Collaboration with peers provides students with the opportunity to consider multiple perspectives and share responsibility in the problem-solving process. While many of the participants in the study pointed to positive examples of peer collaboration, especially in out-of-classroom experiences, others felt that the competitive environment and the wide range of personal standards often resulted in teams that did not collaborate well. Therefore, instruction in communication and teamwork skills such as valuing multiple perspectives, active listening, sharing knowledge and conflict resolution would most certainly improve teamwork skills in the academic environment and into the workplace.

Participants in the current study reported the benefits of feedback across both the technical and non-technical learning outcomes. Specifically, professors, mentors and supervisors played key roles in helping students and early career STEM professionals develop conceptual understanding of technical topics by clarifying information or misconceptions, providing suggestions for locating and organizing data, asking open-ended questions for problem-solving, and giving detailed instructions and comments on presentations, technical writing and assignments. Consistent with the literature, results of the research suggest that industry-related experiences such as internships help students to gain self-confidence by aiding in the formation of their professional identity (Hunter, Laursen, & Seymour, 2007). In addition, many supervisors served as role models for effective teamwork skills, sharing information and valuing the need for life-long learning. Participants in the study noted that the best supervisors provided a balance of letting them try new tasks and providing suggestions or feedback.

2. Implications for Undergraduate Education

Accreditation agencies and professional societies are continually evaluating the changing needs of industry and provide academia critical insights into the knowledge, skills and behaviors needed in the STEM workforce. STEM educators rely on these insights to inform curriculum development and to ensure that graduates are meeting an acceptable level of quality in their education. Understanding how STEM professionals learn the competencies needed for practice enables STEM educators to develop curricular and out-of-classroom activities that provide positive environments and practices for learning.

STEM educators should consider three factors when designing curricular and other experiential learning activities: creating intentional learning environments that address students changing learning needs, providing authentic problems that increase in complexity over time, and engaging in continued and multi-faceted feedback to students' work.

The study suggests that students learn new information, skills and behaviors when they have the opportunity to explore and make mistakes without negative consequences. Therefore, first year STEM curriculum should include these types of exploratory environments that are equipped with tools, equipment or software relevant to the domain. Vicarious learning, guidance and feedback from professors and mentors provide the support students need in the early years to develop a sense of self-efficacy and conceptual understanding of technical topics. Providing opportunities for senior students to mentor first or second year students could be an effective mechanism for this type of vicarious learning.

As conceptual knowledge grows, students need opportunities to master concepts and skills through repetition. In second and third year curriculum, the types of problems should increase in complexity and should focus on the principles-level of understanding. Results of the study suggest that academic institutions may not be doing a good job of teaching teamwork and communication. Professors should provide direct instruction on teamwork and communication skills, especially valuing multiple perspectives, conflict resolution, and active listening. Students should be given the opportunity to practice these skills and to gain feedback from both peers and professors as to how they can improve.

Finally, senior-level courses should include open-ended problems that require students to collect, organize and analyze data from multiple sources. Educators should include more "real world" problems into the curriculum and provide relevant feedback throughout the problem-solving process. At this phase, students should be able to integrate conceptual knowledge with principle-level understanding in order to solve authentic problems. Teamwork, technical writing and presentations should be included in the curriculum and students should be provided feedback throughout the process.

3. Implications for Industry

The original motivation for this research was to understand the discrepancies between those who believed that the U.S. is lacking in the number of qualified STEM workers and the conflicting evidence of STEM students who graduate without jobs. The discrepancy suggested that STEM graduates may be lacking the specific competencies needed for STEM practice. The purpose of the study was to understand how the identified learning outcomes were used in the workplace and how early career STEM professionals develop these competencies.

Results of the study suggest that academic institutions are doing a good job teaching the fundamental math, science and engineering principles needed for STEM practice. However, they are not able to teach industry-specific skills due to the high costs of technical equipment, tools and custom software. Internships and co-ops play an important role in filling this gap by providing exposure to these technical environments. Industry could also help bridge this gap by providing academic institutions “real world” problems that could be incorporated into the curriculum, or by donating equipment or software to those institutions.

In addition, results of the study suggest that academic institutions may not be doing a good job of teaching teamwork and communication, or providing students insight into contemporary issues and new developments in science and technology. Industry partners can offer to give technical talks about current technology or can invite student groups for facility tours to give exposure to modern technological tools. In addition, internships and co-ops give students the opportunity to learn professional skills and practice teamwork and communication skills with practicing STEM professionals.

E. Future Research

The study examined how early career STEM professionals perceived the way they learned the skills and competencies needed for practice. 17 of the 18 participants graduated from the same large research institution while one participant graduated from a different large research institution. Therefore, many of the participants attended the same classes and may have had the same professors, leading to similar learning environments and pedagogies. A study that includes participants who graduate from a broader range of higher education institutions could provide additional insights into the various learning experiences of STEM professionals.

Additionally, STEM professionals who participated in other experiential learning experiences such as study abroad, service learning, or relevant student groups may provide insights that were not discovered in the present study. Because of the strong focus on communication skills, these experiences may lead to greater self-efficacy in those areas identified as weaknesses by current participants. A 2015 survey conducted by the Gates

Foundation indicated that only 14% of professors incorporate experiential learning into their teaching practices. Future research could further examine the barriers for adopting these pedagogical approaches (FTI Consulting Agency, 2015).

Finally, the interview data provided the rationale for developing a new, multi-phase model of learning. This model needs further exploration to either support, refute or modify its claims. In a 2011 report from the Research Council of Norway, Klette emphasizes the importance of educational research as, "a multidisciplinary field where different theories should work in concert". She notes that, "theory nurtures our ability for recognizing complexity. One benefit of theory is to show that what appears on the surface to be simple matters of empirical investigation, on a deeper level, turns out to be complex and subtle. It is a merit of theory to push for a deeper understanding of the acquisition and not to relax before we have a complete analysis of what a student does and what goes on inside his/her head as (s)he for example acquires a new skill" (p.5).

F. Conclusion

The study explored the perceptions of 18 STEM professionals to understand their perceptions on learning the skills and competencies needed for STEM practice. Their stories elucidated the variety of ways that students learn the key STEM learning outcomes both within the academic environment and through other problem-based learning environments such as makerspaces and internships. These insights can provide educators guidance for improving STEM learning through the development of environments and pedagogical approaches that promote creativity, innovation, mastery and integration of technical and non-technical knowledge, skills and behaviors.

In order to prepare STEM professionals who will be able to meet the scientific and technological challenges of the 21st century, educators and industrial partners need to work together to identify, communicate and teach both technical and professional competencies. Results of the study suggest that educators should use a multi-phase approach that takes into consideration the developmental nature of student learning. This approach should provide opportunities for exploration without fear of negative consequences, mastery of concepts without penalty for "re-trying", and integration of knowledge, skills and behaviors in the solving of relevant problems. In addition, educators need to provide instruction on key components of teamwork skills such as valuing multiple perspectives, active listening and conflict resolution. These approaches must be institutionalized within the framework of the science and engineering programs.

Industry must continue to serve as partners by communicating the changing technical and business needs to educational institutions. They can provide "real world" projects for faculty to use in problem-based learning courses or donate equipment or software so students to learn new technologies. They can also commit to providing more internships, co-ops or job shadowing programs that provide students with hands-on experience within the context of the professional environment and the opportunity to learn teamwork and communication skills with other STEM professionals. Finally, employers should remain open to the possibility that students who have participated in problem-based learning may have acquired many of the skills and competencies that are provided through internships. A deeper understanding of how the learning outcomes are achieved, such as that provided by this dissertation, will help educators and employers navigate the constantly changing STEM landscape to educate students with the skills and competencies needed to solve the country's most challenging problems.

APPENDIX A

PARTICIPANT EMAIL

Dear XXXX:

Thank you so much for being willing to participate in my dissertation research. Here is a little background about the study:

The purpose of this study is to explore the ways in which early career STEM professionals gain the skills and competencies needed for STEM practice.

With your permission, I would like to ask you information about your current professional position and various learning experiences that you had when you were a student. Specifically, I'm hoping to answer the following research questions.

1. What are the qualitatively different ways that early career STEM professionals experience the central STEM learning outcomes in the workplace?
2. How early career STEM professionals, gain these skills and competencies?
3. What early career STEM professionals perceive to be the critical factors that contributed to their ability to develop the skills and competencies necessary for STEM practice?

The interview consists of 11 questions--9 of these have 3 parts that address the above research questions. Usually, the interviews are usually done in person and take about 1- 1 1/2 hour, and I am happy to travel to you. Or, in a couple of instances, participants were across the country, so I sent them the questions via email and then we connected by phone for follow-up clarifications.

In addition, there is a very short (1-2 minute) demographic survey as well as a participant consent form (necessary for any qualitative research at UMass).

I have a very flexible schedule through the summer, so please let me know what would work best for you.
Again, thank you so much for your participation.

Cheryl Brooks

APPENDIX B

COMMON METRIC OF STEM LEARNING OUTCOMES

Outcome	Science	Technology	Engineering	Math
Ability to apply mathematics, science, and/or engineering principles	X	X	X	X
Ability to identify, formulate and solve complex problems	X	X	X	X
Ability to communicate effectively (both orally and written)	X	X	X	X
Ability to function on multidisciplinary teams	X	X	X	X
Understanding professional and ethical responsibility	X	X	X	
Ability to locate, organize, analyze and interpret information/data from multiple sources	X		X	
Knowledge of contemporary issues and new developments in science and technology		X	X	X
Ability to use the techniques, skills, and modern technological tools necessary for solving complex problems	X	X	X	X
Recognition of the need for and an ability to engage in life-long learning	X	X	X	

APPENDIX C

INTERVIEW QUESTIONS

Relevant to your current professional position:

2. What does it mean to be able to (a-i) in your professional capacity?

3. How did you develop this ability?

4. What are the critical factors that contributed to your ability to (a-i)?

    a. Ability to apply mathematics, science, and/or engineering principles
    b. Ability to identify, formulate and solve complex problems
    c. Ability to communicate effectively (both orally and written)
    d. Ability to function on multidisciplinary teams
    e. Understanding professional and ethical responsibility
    f. Ability to locate, organize, analyze and interpret information/data from multiple sources
    g. Knowledge of contemporary issues and new developments in science and technology
    h. Ability to use the techniques, skills, and modern technological tools necessary for solving complex problems
    i. Recognition of the need for and an ability to engage in life-long learning

5. Are there any knowledge, skills or competencies that you use in your professional life that you wish you had learned as a student?
6. During the hiring process, how did recruiters or hiring managers evaluate your knowledge, skills and behaviors?

APPENDIX D

PARTICIPANT SURVEY

Early career STEM professionals

1. In what month and year did you graduate?

- [ ] May 2014
- [ ] Feb 2014
- [ ] May 2013
- [ ] Feb 2013
- [ ] May 2012
- [ ] Feb 2012

Other (please specify) ____________

*

2. What was your major?

____

3. What was your minor?

____

4. Did you participate in any of the following: (check all that apply)

- [ ] iCons
- [ ] M5
- [ ] Internship

Other (please specify) ____________

5. What is your gender?

- [ ] Female
- [ ] Male

6. What is your ethnicity? (Please select all that apply.)

- [ ] American Indian or Alaskan Native
- [ ] Asian or Pacific Islander
- [ ] Black or African American

- [ ] Hispanic or Latino
- [ ] White / Caucasian
- [ ] Prefer not to answer

7. Are you currently employed in the STEM field?

( ) Yes

( ) No

8. What is your official title?

9. About how long have you been in your current position?

Years

Months

10. Have you worked at other positions within this company?

( ) Yes

( ) No

Other (please specify)

APPENDIX E

PARTICIPANT CONSENT FORM

Description: You are invited to participate in a research study on learning outcomes in the STEM fields. From the information collected in this research, I hope to learn more about how the central STEM learning outcomes are experienced in the workplace, the circumstances and mechanism by which the learning outcomes were achieved, and the motivations for learning these outcomes.

Purpose of the Study: The purpose of this study is to explore the ways in which early career STEM professionals gain the skills and competencies needed for STEM practice.

Procedures: With your permission, I would like to conduct a survey to collect demographic and background information about you, including employment information and information about various learning experiences that you had when you were a student. In addition, I would like to conduct an interview, which will be recorded and transcribed in order to determine:

1. What are the qualitatively different ways that early career STEM professionals experience the central STEM learning outcomes in the workplace?
2. How early career STEM professionals, gain these skills and competencies?
3. What early career STEM professionals perceive to be the critical factors that contributed to their ability to develop the skills and competencies necessary for STEM practice?

Risks and Benefits: There are no anticipated risks associated with this study. You will not receive any direct benefit from participation. The results of this research may be helpful in mentoring future STEM students in the workplace. However, I cannot guarantee that you will receive any direct benefits from participation in this study.

Time Commitment: The survey will take approximately 5 minutes to complete. The interviews will last approximately 1-2 hours.

Participant's Rights: Participation in this research is entirely voluntary. You are free to discontinue participation or withdraw from the research at any time without consequence. In order to protect your privacy and confidentiality, I will store the recorded interviews in a secure, locked box and will destroy them after the research is complete. In addition, I will use a pseudonym in any publications or unpublished documents that results from this research.

Contact Information: If you have any questions or concerns about this study, its procedures, risks or benefits, please contact my dissertation advisor, Dr. Benita J. Barnes by phone at 413-545-1083 or email at barnesbj@umass.edu, or Dr. Linda Griffin, Associate Dean for academic Affairs, email: lgriffin@educ.umass.edu phone: 413-545-6985.

Thank you,
Cheryl Brooks , (413-545-2386), brooks@ecs.umass.edu
Signature of Participant Date

_______________________________________ _________________________________

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