AN EXPLORATION OF STUDENT RESPONSE TO AN ACTIVE LEARNING ENVIRONMENT IN AN UPPER-LEVEL QUANTUM PHYSICS COURSE

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Education in Education

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DEDICATION

I dedicate this work to my wife, Susan, who believes in me and keeps my feet on the ground, and to my daughter, Grace, who reminds me daily that this journey is worthwhile.
ACKNOWLEDGEMENTS

As I take a break from the relentless grind that defines a work of this scale, I reflect on those who have made this journey possible. In that space, I would like to communicate the reality that this work is not my own, but it belongs to all of those who have given their insight, knowledge, and compassion in support of me and my work. It is my hope that our continued work will cultivate an educational environment that elevates the human experience. It is this hope that has driven me in this work. That, and hard deadlines.

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ABSTRACT

The passive-lecture model pervades the post-secondary STEM environment, though little evidence supports it. While more interactive models are not uncommon, especially for smaller classes, they often only marginally address deep concerns about the passive-lecture model, such as personal experience, group interactions, etc. While active learning approaches are being used more, little is known about how advanced students respond in STEM to long-term interventions. This case study qualitatively explored response to a semester-long active learning intervention in one upper-level quantum mechanics course, from an engagement perspective.

The study identified ten themes that described participant response: Time Pressure, Vibrancy, Group Activities, Public Work, Individual Work, More Natural Over Time, Students Differ, Community Matters, Hard but Rewarding, and Implementation Difficulties. These results largely align with existing literature on the effects of active learning. However, the results also reflected aspects of the advanced STEM learning experience that are unique, such as motivation, community, student preference, and meta-cognition. These results indicate more inquiry is needed into factors surrounding the advanced STEM student learning experience if we are to improve the learning environment.
CHAPTER ONE

INTRODUCTION

Background

The longstanding traditional education model consists of a single expert transferring knowledge to 20-200 students (or more) in an environment that most closely resembles the modern theater. While this model may have been effective for personally transmitting information to large groups at the dawn of the industrial revolution, the purposes (and tools) of education have developed much since the 1870s (Khan, 2012b). However, the environment assumes and promotes students as passive recipients of knowledge. With the dawn of progressive education in the modern era, more active educational models evolved, having four advantages over a passive-lecture model: The students practice the skills learned, students can learn at their own pace (Khan, 2012c), students’ attention stays engaged (Middendorf & Kalish, 1996b), and the students explore varied levels of knowledge widely operationalized by Bloom’s (1956) taxonomy (Dewey, 1959; Phipps, Phipps, Kask, & Higgins, 2001).

To address this changing landscape, many innovative progressive effective teaching practices have been explored, identified, and implemented, especially at the K-12 levels (S. V. Chasteen et al., 2015). These progressive practices include approaches like integrating mastery learning, multimedia content, group learning, and increased focus on good teaching practices. These practices have been shown to improve various aspects of student growth, from conceptual understanding to persistence to attitude.
Mastery learning has been shown to improve student conceptual mastery and attitudes, especially when using good practices such as frequent and focused feedback (Kulik, Kulik, & Bangert-Drowns, 1990). Multimedia content has been shown to capitalize on the ability of the brain to process visual and audio input in parallel, in improving conceptual understanding (R. E. Mayer, 2002) and student satisfaction (Pedra, Mayer, & Albertin, 2015). Group learning has shown positive effects on student understanding and attitude, as well as other positive social-based characteristics, when conducted effectively (Guskey & Pigott, 1988; Shimazoe & Aldrich, 2010). Finally, good teaching practices, such as clarity, illustrations, engagement within the classroom community, and technical expertise have always been effective (Lowman, 1984), but recent work in quantitative research has demonstrably shown the positive impact of these practices (Fitzpatrick, 2014).

Active learning is one such progressive teaching approach that has garnered particular attention (Freeman et al., 2014; Pang, 2010; Prince, 2004). Active learning is an approach that uses exercises in which students participate during learning (Prince, 2004). While active learning often includes activities that requires student physical interaction, it may also include activities that solely require student mental focus: This distinction is often referred to as hands-on vs. heads-on engagement (Hake, 1998).

Integration of active learning at the post-secondary level, on the other hand, has been limited. The seemingly inconsistent perspectives of teaching and research expectations for faculty is well known especially within the STEM disciplines. There is renewed interest in promoting progressive practices at the post-secondary level, and it
seems to be working. Top-tier research institutions, like Purdue and Virginia Tech now have Engineering Education departments and graduate degrees, reflecting the growing demand for experts in STEM education practices. While research has been exploring technical introductory class effectiveness, much less has been done to address more advanced environments (such upperclass students or graduate courses).

Increasingly, STEM courses are integrating active learning environments into existing courses, demonstrating significant improvements in content mastery (S. Chasteen & Perkins, 2014; Prince, 2004). Active learning engages behavioral, affective, and cognitive aspects of the student in the learning process, through structured activities that promote more advanced cognition, often eliciting emotional response (Zull, 2006). Though active learning is a broadly-defined term—this study will follow Prince’s definition of a learning approach that uses participatory exercises (2004).

Statement of the Problem

While the traditional lecture model is used extensively in undergraduate STEM classes, active learning has been shown to be more effective by almost any measure; mastery, motivation, and short-term retention, to name a few (Prince, 2004). Physics education research is one of the most prolific fields within post-secondary STEM education, and substantial research has examined the effects of active learning on introductory physics classes (Hake, 1998; Prince, 2004). However, relatively little research has explored the impact of active learning on upper-level classes (S. V. Chasteen, Pollock, Pepper, & Perkins, 2012). While quantitative methods are often used
to investigate cognitive responses (such as retention, mastery, or misconceptions) to interventions (Prince, 2004), some researchers suggest a qualitative approach might provide a richer, more accurate and informative model of students’ experience (L.R. Gay, 2009a).

With national calls for improved education for STEM majors, including at the upper levels, the need for effective teaching practices is essential for accomplishing this goal (AIR, 2018). Active learning is one of the most effective classroom techniques, especially for conceptual mastery in STEM majors. While much of the research focus in STEM fields has been on improving the more widely attended and visible introductory classes, upper-level classes are integral to student development. In fact, if one takes the approach that students mature through their college experience, upper level courses are taken by students with more developed cognitive patterns. Hence, these courses provide a venue for further developing and strengthening higher level skills, such as critical thinking and job-related skills. Since there are professional calls for more advanced cognition for graduates, it is reasonable to suggest that upper-level courses provide the ideal environment for cultivating students that more fully meet industry expectations.

In addition, incoming graduate student mastery and meta-cognitive practices have been observed as falling short of instructor expectation (Carr and McKagan, 2009). Given the value that active learning approaches seem to provide physics majors in conceptual mastery, more widespread use of active techniques may help overcome the gap between graduate expectation and undergraduate achievement. Moreover, increased implementation of active techniques in undergraduate curriculum may provide templates
for implementation in graduate courses, where they have the potential to improve conceptual mastery, motivation, self-regulation, and meta-cognition.

Finally, even without these external influences, a central aspect of education research is to identify and promote effective practices that cultivate and empower student growth. With the strong evidence supporting active approaches to STEM content, it seems entirely consistent with educator intent to integrate active practices wherever they can support student growth, or at least to explore the effects of progressive ideas and practices. This focus on continual inquiry and improvement is at the heart of research-based scholarship and progress in education.

Despite this need to better understand the behavioral, emotional, and cognitive aspects of student experience in an active learning class (Fredricks, Blumenfeld, & Paris, 2004), there is relatively little qualitative research that explores the overall student experience in upper-level classes, especially during the transition from traditional to active models (S. V. Chasteen et al., 2012). Therefore, there is a need to more closely examine overall student experiences during these transitions as emotional response influences many aspects of cognitive growth. Moreover, complex engagement with material creates more complex brain structure over time (Zull, 2006). And, simple adjustments to rehearsal techniques have been shown to improve memory (Miller, 2011). In other words, student engagement is critical to cognitive growth.
Statement of Purpose

In response to this gap in the literature, this project explored the overall student experience of an upper-level physics transformation. In so doing, findings from this study may help inform a richer understanding of the student experience and to inform further quantitative and mixed-methods research on the effects of an active learning environment for upperclass STEM students. More specifically, students respond in various ways to the classroom environment, effecting traits such as preparation, stress, and motivation. For the purposes of this study, students’ experiences of the education environment are characterized as behavioral, emotional, or cognitive (Fredricks et al., 2004). Behavioral characteristics refer to student actions and involvement in classroom activities. An example of behavioral response might be an increase in preparation for class, knowing that familiarity with some content is required for successful activity participation. Emotional characteristics refer to student feelings, such as “frustrated,” “stressed,” or “intrigued.” An example of emotional response might be decreased stress during class, since students have already previewed material, and since collaborative activities provide a relaxing, but engaged, social experience. Finally, cognitive characteristics refer to mental states, such as persistence, metacognition, and motivation (Fredricks et al., 2004). An example of cognitive response might be increased motivation, due to student curiosity being awakened during a computer simulation that explores quantum behavior, effectively providing an experience that reinforces intrinsic (as opposed to extrinsic) motivation (Dweck, 1986).
Research Questions

This study qualitatively investigated participants’ experiences during an active learning environment. Participants were upperclass STEM students and the course was upper-level quantum mechanics. There were two main goals to this study. The first goal of this study was to explore the experiences of students in upper-level quantum mechanics resulting from a course transformation from a traditional classroom environment to an active one. The second goal was to identify the most significant active learning exercises during students’ experience. Answers to these questions may inform the implementation of active learning exercises for upper-level STEM educators.

Based on these goals, the following research questions guided this study:

1. How are upperclass physics students’ experiences shaped by active learning interventions in a core class?

2. Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?

More specifically, the study used a case study methodology to explore participant experiences, bounded by one semester in a quantum mechanics course. The study explored participant and instructor experiences of active learning implementation, as well as significant characteristics of the course environment, due to active learning. Data was collected through class observation, two individual interviews (for each student), and a class-wide focus group. The setting for the study was a small upper-level quantum mechanics class, offered at a large Rocky Mountain land-grant university. The study implemented the intervention for one semester, covering the span of 15 weeks.
Positionality Statement

It is important to note that a postpositivist framework approach has shaped this study. My esteem for the engineering discipline fuels my trust in clarity and the scientific method, wherever possible: A modernist epistemology guides much of this study. In addition, my esteem for scholarship fuels my desire for impartiality and unbiased research, as an axiological guide. However, my esteem for the profound complexity of the human experience fuels my skepticism in an absolutely modernist approach: Regarding human experience, my ontological beliefs affirm the presence of multiple realities, based on participant experience and interaction—a view that might be more at home in a social constructivism framework. Finally, I believe that some aspects of this research are clear and objective, while many others are nuanced, subjective, and emerging: Methodologically, I’ve tried to strike a balance between the two, in a way that respects the science and humanity of the research experience.

I believe that explicit, authentic positionality discussion properly framed the lens through which I perceived this study. Given my background, the study methodology, and the study focus, I found a postpositivist framework to be the most appropriate approach. I identified areas where concrete conclusions may be established, and protected areas where the complexities of the experience cannot be reduced. I believe understanding of the human experience must be explored delicately, respectfully, and with a loose grasp.
My roles as a researcher was complicated by my concurrent role as a Graduate Teaching Assistant (GTA)\(^1\) in the class, creating a challenge for this study. While these roles positioned me in close relationships with the participants, it also exposed the study to ethical and validity considerations. On the other hand, I had recently taken the course (and its follow-up course) successfully, which provides a fresh perspective on the student experience of learning quantum mechanics. The possible interaction of these roles required constant and careful bracketing, as well as careful study design.

In addition, I would also like to express the positionality that will inform my approach to the Literature Review. My background in mechanical engineering, ministry, education, and physics have influenced my perspective for the Literature Review. My experience as an engineer has trained me to develop and follow research selection criteria. My background as a teacher provides a lens through which I can see the complex latent constructs under the seemingly simplistic quantitative advantages of active learning. My experience as a minister guides my careful approach to an individual’s sacred experience, where the respectful observer must dance carefully with meaning: “What is the truth that each of these resources uncovers?” Finally, my experience as a scientist has made me relentlessly curious, with a deep-seated trust in well-founded logic: I am able to read an argument that opposes my view with relatively little bias holding on to what is believed, rather surrendering to the illumination of reason. A modernist epistemology guides this literature review.

\(^1\) The GTA position is a paid role, with a weekly 4-hour responsibility for reviewing and grading homework and occasional high-stakes quizzes.
Framework

The conceptual framework provides a model for understanding student experience of an active learning classroom environment (Creswell, 2013b). Three major concepts, with firm empirical foundation and simplicity of implementation, as implemented in this study: Active exercises, cooperative learning, and pre-lecture videos (S. V. Chasteen, Perkins, Beale, Pollock, & Wieman, 2011). Exercises include simulations, student exploration, and the practice of new skills. Cooperative learning enables students to learn, explain, and explore together. Finally, pre-lecture videos facilitate student preparation for class, and reduce the need for in-class content presentation. Exploring student experience provides an accessible window into significant influences of these concepts.

The concept map (Appendix A) illustrates the core concepts that were explored, as well as their relationships with one another. Arrows indicate direction of influence. Solid lines indicate concepts that are within the scope of this study, while dashed lines indicate those concepts with only incidental connection. Incidental concepts include topics such as motivation, institutional impact, and mastery. This study will not examine other impacts to student experience, such as course content, environmental factors, or any factors outside the bounds of the case.

Limitations and Delimitations

Due to the structure of this study, several limitations should be noted. The content of this course is quantum mechanics, which may not represent student
experiences in other upper-level Physics courses. However, the critical factors that distinguish quantum mechanics are relatively constant across upper-level Physics courses, such as Electrodynamics, Special Relativity, and Particle Physics. All courses are small, attended mostly by Physics majors, require high-functioning prerequisite knowledge, and explain phenomenon not obviously observed in daily life (S. V. Chasteen et al., 2015). Moreover, the field of this study is Physics, which may not represent student experiences in other STEM fields. However, the experiences and cognitive skills required in Physics are very similar to those required in the hard sciences and mathematics. Mainly, students experience traditional models, succeed in rigorous analytical classes, and develop increasingly technical skills. Finally, the environment of this study is a small class, which may not represent student experiences in larger classes. Discrepancies in outcomes between small and large classes are fairly common, whether the measured outcome is mastery, affect, or some other characteristic. However, the bulk of upper-level technical courses are small classes, simply due to the highly technical nature of the class. Hence, analysis is expected to be generalizable to other STEM upper-level classes, simply because most upper-level classes are small.

In addition, several delimitations should be noted. First, and most importantly, the influence of active exercises, and active exercises only, on the students’ experiences will be studied. This delimitation provides focus and clear boundaries during a rich exploration of the students’ engagement response. Related to focus, this study will not explicitly explore, several concepts: institutional effects, educator effects, mastery-
learning, critical thought, introductory STEM course environments, environmental factors, non-STEM fields, and motivation.

**Definitions**

*Active Learning*— An approach that uses exercises, in which students participate, during learning (Prince, 2004).

*Motivation*— A psychological factor that describes a student’s reason for persistence (Dweck, 1986). For the purposes of this study, this concept will be described as a cognitive construct (Fredricks et al., 2004).

*Critical Thinking*— A characteristic that describes complexity of thought (Moore, 1994).

*Mastery-learning*— An approach that requires students to master one topic before moving on to the next (Kulik et al., 1990).

*Cognitive Load Theory (CLT)*— A cognitive-based theory that models optimum information processing of the human brain (R. Mayer, 2009).

*Transformation*— The process of creating an active learning environment for a course, based on learning objectives and feedback (S. V. Chasteen et al., 2011).

*Cooperative*— In layman’s terms, students succeed together; the opposite of competitive (Hattie, 2016).

*Collaborative*— In layman’s terms, students learn together; the opposite of isolated (Hattie, 2016).
Passive vs. Active and Lectures

While a fuller exploration of lecture-based models is provided in the Literature Review, a brief discussion of what is meant by a passive-lecture model provides a framework for understanding later discussion about active learning. To contrast the potential value of active learning, the approach is compared throughout this to the more passive, lecture approach. The passive, lecture approach is typified by the “sage on the stage,” where one expert disseminates content knowledge to a large listening crowd. Slides or board explanations are often used and derivations are common.

While the passive approach is still widely used—examples may be found at MIT’s OCW or Great lectures—lectures in smaller classes, which are not uncommon in upper-level physics, may involve more dialogue or questions between student and instructor. While this dialogue model may cultivate a better educational environment, in terms of cognitive and affective response, it shares a core characteristic with the passive model: Students do not have a close personal experience with the natural laws explored, which is a fundamental characteristic of active learning. A broad range of education theory and cognitive science have demonstrated that active learning is a critical aspect of deep learning. Herein lies a core argument for active learning—it provides students the necessary experience for deep learning.

While the characterization of a truly passive lecture may not be an accurate assessment of the current norms of small classes in a university, it does provide a model against which active learning practices can be compared. Moreover, while more progressive lecture-based techniques may mitigate key concerns associated with a passive
lecture model, research suggests that active exercises are more effective for cultivating
dee and accurate learning. That is not to say that lectures are useless, rather that they—
like active practices—fulfill only one aspect of a student’s education. A growing base of
research into student learning outcomes in physics education resonates with this
assessment.

With this in mind, the passive / active dichotomy may be thought of as extremes
along an axis, where active or passive ideals define the extremes. Various classroom
activities are oriented along the axis, some more active and some more passive.
According to this model, the appropriate activity for the lesson intent may be chosen,
acknowledging that theory and research concur that more active approaches are largely
more effective in conceptual growth, amongst other measures. In particular, an
interactive lecture could be perfectly appropriate when lecture is appropriate (e.g.
scaffolding expert-like approaches to new problems, or asking thought-inducing
questions to students and evaluating their responses), as it reflects a lecture-based
approach that is further along the active axis, hence probably more effective. And, for
introducing students to new physical concepts, active approaches may provide a good
foundation for subsequent deep learning.

Evidence-based Practices, Tradition, and Progress

While many of the techniques that current research shows cultivate student
growth are active, the broader term often used in describing these progressive ideas is
evidence-based. The difficulty of this term is that it implies that if a practice is evidence-
based, alternative practices do not have supporting evidence in the research. In reality,
this is seldom the case, as the relative effectiveness of varied practices are often reflected along a continuum in complex ways. For example, Practice A may be marginally more effective in promoting conceptual mastery, but Practice B may show demonstrably superior affective responses.

Because the term *evidence-based* may conjure a false dichotomy, it will be largely avoided. Instead, the term *progressive* will be used, defined as a modern practice that engages the learner in their own growth, based on largely constructivist theory. This will serve as a foil to *traditional practices*—those practices which have their justification in their historical use in the college classroom.

Once again, the progressive and traditional ideals may be viewed as directions along an axis, where more progressive is less traditional, and vice-versa. It should be noted that their orientation along the axis is not based on some ontological position, but is defined by the practitioners justification in their implementation, and the context in which they are applied. Moreover, specific practices that are currently seen as traditional were at one point, inevitably, seen as progressive. In other words, the instructor who lectures because he has always lectured, and it has worked just fine, may be embracing a more traditional approach. On the other hand, the instructor who lectures in 10-15 minute chunks because she finds short explanations and discussion properly model expert-like thinking on a particular idea, based on the research she has read, reflects a more progressive approach.

Implicit in this approach is the relative standing of various interventions. While both instructor perception of student achievement and small class sizes are both
progressive changes to the class, the former demonstrates an effect size of 1.62 while the latter demonstrates an effect size of 0.21, in terms of growth in conceptual mastery (Hattie, 2016). While both may meet the criteria of a progressive approach, one is clearly more effective, all other things being equal. Once again, more in-depth discussion of education research is reserved for the Literature Review, but deserves discussion here to provide a context for use of the progressive throughout this paper.

Finally, several features of this progressive approach should be noted. First, active learning sits squarely within a progressive approach, though not all progressive approaches would necessarily be interpreted as active (as mentioned in the opening paragraph of this section). For example, well-developed multimedia presentations may not be defined as active by some, but certainly are progressive. Second, the weight of current education research and scholarship focuses on quantifying the value of progressive approaches, often comparing them to traditional techniques. For many, this reflects the growing knowledge of the scholarly community on what cultivates student growth. Third, there are inherent assets and liabilities to both traditional and progressive approaches to education, which fall outside the scope of this research (e.g. the Tuskegee Syphilis study was seen by many—including those in the educated black community—to be progressive in its day). Finally, with points two and three notwithstanding, and most relevant for the purposes of this paper, progressive approaches will describe those practices which current research indicates are more effective than traditional techniques in some measurable aspect of student growth.
Assumptions

Several assumptions were made during research design. First, active exercises, cooperative learning, and prelecture videos actually promote active learning and support learning targets. Second, participants exhibit high engagement, sampling rate, and willingness to honestly report. Third, the instructor explicitly and implicitly supports the active learning intervention and effectively implements activities and is supported by the researcher in matters relating to pedagogy and class administration.

Significance

A qualitative exploration of upperclass physics students and their experience of an active learning intervention improves understanding of both student experience, as well as the most influential factors in that experience. The implications at an institutional level are four-fold: First, as institutions promote progressive and learner-centered initiatives, especially within STEM fields, the degree to which their initiatives are effective will rely heavily on understanding student transitions to active learning, especially at the upper-levels, where norms have been established. Second, undergraduate student engagement will be affected by their experience in the classroom, which in turn influences student success and retention rates. Third, upon arrival to college, students expect better teaching than ever before (Wesch, 2011). In the increasingly competitive world of post-secondary education, those universities that do not provide excellent education will find students increasingly choosing to attend universities that do (Vredevoogd, 2010). Finally, as active learning implementation increases its
saturation in STEM courses, factors surrounding upper-level Physics environments will become more significant.

In summary, the growing interest in post-secondary STEM education improvement reflects gains seen in K-12 education, based on progressive teaching techniques. Active learning has shown improvements in various areas of student development, and the physics education field has explored much about how it affects conceptual mastery. However, there is still much we do not understand about how upper-level STEM students respond to various active practices cognitively, emotionally, and behaviorally. Qualitative exploration of student engagement provides insight into the experiences observed and reported in an active advanced physics environment. These findings may add to our understanding of active learning and may help build progressive interventions for institutions seeking to serve their STEM students.
CHAPTER TWO

LITERATURE REVIEW

Approach

The purpose of this literature review is to explore research that addresses active learning and engagement in upper-level physics. The literature review serves to identify the existing state of quantum mechanics education research, gaps in the existing literature, the contribution of this paper, and opportunities for future research (Ravitch & Riggan, 2016). The approach will reflect a phenomenological approach to knowledge construction, as outlined in Randolph (2009). Hence, the literature review will start with a high-level exploration of education theory, then narrow focus to an examination of how active learning affects student engagement in upper-level physics. Finally, the rather extensive scope of the Literature Review reflects my journey as a scholar in understanding the theoretical and empirical research that surrounds a cohesive understanding of active learning in the STEM classroom.

This approach to cover both the breadth and depth of relevant literature will be accomplished by a four-level progression in scope (Appendix B). At level one, I will briefly discuss applicable education theories. Next, various aspects of active learning and other progressive practices will be explored. From there, the approach will turn to physics-related research. Finally, the fourth level will examine unique aspects of upper-level physics students within the context of existing active learning research.
The driving question of the literature review is the following: “What does existing literature say about factors surrounding student engagement in an upper-level physics active environment?” The focus of the literature review is to identify research outcomes that directly address central factors in this case study. Specifically, what does existing research say about student experience in physics upper-level active learning classrooms? Research methods of existing literature will be critiqued, insofar as they affect outcomes: Quantitative methods dominate the existing physics education landscape. Some review of theory is appropriate, as this qualitative approach may find that features of upper-level physics active learning need to be re-situated in existing constructs. Finally, some aspect of practices will be addressed, especially in the Discussion section, as operationalization will inevitably be an important component of student experience.

The methodology of selecting the literature is a twofold purposive sampling. First, for topics that relate to concepts undergirding this study (such as cognitive apprenticeship or Kolb’s Experiential Learning Cycle), seminal articles that establish, summarize, or critique the landscape were reviewed. Careful attention will be given in identifying main concepts that influence the topic, even if subtler or more recent aspects of the topic were not explored. Second, for physics education literature addressing active learning in upper-level courses, all cited research was reviewed for significant statements. In addition, references in this literature was reviewed for relevance. The references in those references were likewise reviewed (following a recursive tactic), until saturation characteristics were observed. Minimal electronic database queries were conducted. Keywords in in active-learning physics education literature references that prompted
review were the following: upperclass, qualitative, engagement, long-term, and evidence-based (Randolf, 2009).

**Introduction**

The growth of the internet and the information and multimedia tools that come with it have disrupted the status quo of many industries over the past 20 years, not least of which is education. While the relative merits of more technology in the classroom is undecided, the conversation alone has renewed a focus on characteristics of a good education. That renewed focus has been accompanied by an increasing interest in *science, technology, engineering and math* (STEM) education. While theories of education provide guideposts, there are aspects of STEM education that seem to differentiate it from other fields (Heywood, 2005). In particular, STEM fields focus primarily on conceptual mastery and logical thinking. Yet, relatively little literature has explored the *advanced* STEM students’ cognitive responses to progressive interventions, let alone other engagement indicators, such as affect or behavior (Carr & McKagan, 2009). A more robust understanding of advanced STEM students is needed.

**Education Theory**

Theories of education have been part of scholarly and popular discourse from before the times of ancient Greece (Van Doren, 1992). However, several theories pertaining to education are especially relevant in discussion of active learning in post-secondary environments. Dweck’s (1986) *Motivational Theory* provides insight into how students engage with difficult material, and it provides insight into how aspects of an
active environment may influence student motivation. Kolb’s (1981) *Experiential Learning Cycle* explores stages typical to all learning, and it provides a framework for understanding when active learning interventions may be most effective. Piaget’s *Three Axioms* are a high-level framework for understanding how humans make sense of the world around them, and they provide context for understanding how advanced learners may benefit from active exercises (Kurfiss, 1988). Lave and Wenger’s (1991) *Situated Learning* explores the mechanisms by which beginners become experts, and the theory orients the value of community-based active learning practices. *Cognitive Apprenticeship* extends the age-old concept of trade apprenticeship to development of knowledge-based skills, and it provides a framework through which one may appreciate the value of active learning approaches. Finally, recent findings in cognitive science provide quantitative evidence that measures aspects of each of these theories. This section will briefly explore each of these theories, with a focus on aspects of them that relate to active learning.

**Dweck’s Motivation**

The effects of active learning have been explored and explained within the context of several popular modern learning theories. These theories provide frameworks within which one may more fully understand *Physics Education Research* (PER) approaches to active learning and explore the varied aspects of active learning in STEM. First, Dweck’s (1986) motivation theory proposes an approach to understanding the influence of motivation on learning: learning- vs. performance-goal orientations. Learning-goal orientation describes a desire to build competence, and it provides stability
when faced with failure and challenge—this is sometimes called adaptive motivation. Performance-goal orientation describes a desire to achieve positive judgements or avoid negative ones regarding competence, and it shows susceptibility to failure and challenge—this is sometimes called maladaptive motivation. These orientations directly effect persistence during challenging learning moments. Research into beliefs has revealed that certain learners view learning as understanding via knowledge construction, representing a constructivist learning-goal perspective, whereas other learners view learning as memorization and recollection, or knowledge reproduction, representing a more passive performance-goal orientation. Learners who view learning as a knowledge reproduction task tend not to personalize or internalize the learning experience while learners who are constructivist and oriented towards knowledge construction tend to be inherently progressive, engaged internally, and active in searching for deeper understanding. The connection between an active, constructivist-oriented instructional strategy that engages metacognitive skills activities with various components that are essential for learner success, such as motivation and personal epistemology, is more meaningful for learner development. An essential component of cultivating an adaptive orientation is focus on effort, rather than ability. An adaptive focus asks the question, “What have you done?” rather than “What can you do?”, which requires an inherently active approach to the classroom (Dweck, 1986).
Kolb’s Experiential Learning Cycle

Kolb’s (1981) Experiential Learning Cycle provides a second framework through which one can understand the learning experience (Appendix C). Students move through a four-fold learning cycle, also known as the *experience-interpret-generalize-apply* cycle, as follows: Concrete Experience (CE- laboratories, simulations, etc.), Reflective Observation (RO- discussion, questions, etc.), Abstract Conceptualization (AC- projects, papers, etc.), and Active Experimentation (AE- independent work, case study, etc.). Two of the four cycles, AE and CE, fundamentally involve student action and engagement with learning objectives. Reflective Observation consists of varied reflection and expression of deeper concepts, through discussion, journaling or inquiry: It is in the expression of deeper concepts that one finds an active testing of conceptual structures. Abstract Conceptualization describes the generation of knowledge or production of a final project: Project completion requires an active approach, as the learner must use a heads-on approach to create something new out of existing knowledge. Hence, this model assumes active learning during the entire student growth cycle (Svinicki & Dixon, 1987).

It is useful to note here that Kolb’s model is further divided into two axes (Appendix D). The vertical axis moves between concrete and abstract components of learning and connects CE and AC. The horizontal axis connects RO and AE, and it moves from reflective to active components of learning. One may interpret dominant modes of learning in individual fields as occupying a continuum along these axes. While the Kolb cycle reflects the learning process in all fields, it is expected that some topics are more heavily weighted in one aspect of learning than others. For example, chemists
may often find themselves in CE labs, as they manipulate the natural world. Or, one can easily imagine foreign languages, theatre, and social work environments using very concrete types of expertise. Reflective fields include botany and political science. Active fields include architecture and civil engineering (Kolb, 1981; Svinicki & Dixon, 1987). In general, the sciences, engineering, and economics require abstract types of expertise. Interestingly, it is those fields that demonstrate more abstract characteristics, such as STEM, that seem particularly resistant to active learning practices at the post-secondary level. It should here be noted that while discipline-based education is a rich and interesting field, it falls outside the scope of this literature review.

Piaget’s Three Essential Axioms

Piaget developed a third seminal theory in the philosophy of education. From a global perspective, Piaget suggested that the learner moves from concrete to abstract thought patterns, as cognition grows increasingly complex. Piaget’s theory is founded on “three essential axioms…:

1. Knowing is ultimately based on activity, both physical and mental, an interaction between self and environment.

2. Development is a gradual and progressive reorganization of mental structures used to “make sense” of the world.

3. Learning (other than rote learning) occurs when the learner acts to resolve discrepancies between beliefs and new information which does not fit those beliefs (Kurfiss, 1988, p. 141).
The first axiom is deeply rooted in an active approach to education, where knowledge is built due to active interaction with the surrounding world. The second and third axioms also reflect an active approach to learning, when we extend the definition to ‘heads-on’ as well as ‘hands-on’: The learner is the responsible party in “reorganiz[ing]… mental structures” and “resolv[ing] discrepancies between beliefs and new information…” In summary, Piaget integrates active learning deeply in his theory, “…emphasiz[ing] the active participation of the knower in the process of understanding the world” (Kurfiss, 1988, p. 141).

Lave and Wenger’s Situated Learning

A fourth model that integrates an active perspective in learning is Lave and Wenger’s work on situated learning (Lave & Wenger, 1991, 1998; Wenger, 1998; Wenger, McDermott, & Snyder, 2002). Situated learning suggests that learning happens most effectively in community; learning should be a social rather than a primarily solitary practice. Under this model, discussion and interaction (both active exercises), within a community of experts and learners, are necessary steps in learning. Lave and Wenger (1998) would take their social constructivism model one step further, insisting that true learning is- by definition- a social practice: “Learning is, thus, not seen as the acquisition of knowledge by individuals so much as a process of social participation… This social process, includes, indeed it subsumes, the learning of knowledgeable skills” (p. 3).

Situated learning functions within the context of a larger, more complex model, called a Community of Practice (COP), where learners have a reduced-risk environment in which they may observe experts practicing their trade and be recognized for increasing levels of
expertise and contribution (Appendix E). Learners are provided the status of *Legitimate Peripheral Participants* (LPP), where they may observe core member interactions and discussions, and they may choose to engage with core members in their own time, as they develop the skills needed to act as legitimate active members. The community practices *benign neglect*, leaving LPPs on their own to advance in knowledge. Learners increase participation with the surrounding community in incremental steps, as their competence is tested and proven. It is through communal engagement that recognition is achieved and that knowledge grows in complexity. A fundamental component of the COP model is that successful members are characterized by a desire for legitimacy within the broader community: This model promotes internal motivation, as competency-based, as opposed to performance-based, motivation drives increasing expertise, which facilitates increasingly central roles in the community (Lave & Wenger, 1991) (Lave & Wenger, 1998; Wenger, 1998; Wenger et al., 2002).

The COP model initially described professional trade communities and how novices and experts moved within them (Lave & Wenger, 1991). Since then, the COP model has been used to describe many various professions, as well as the academic community (Cox, 2005). Some experts suggest that existing institution norms strongly handicap student social growth, both within a professional community such as engineering and within the academic community itself (Day, 2011; Knight & Novoselich, 2017; Lave & Wenger, 1991). Nevertheless, the COP model provides a framework through which one can interpret social aspects of mastery and engagement in a college setting.
Cognitive Apprenticeship

A modern constructivist theory that addresses the STEM priorities of education is cognitive apprenticeship. This model likens the classroom experience to trade apprenticeships of old. However, the ‘skill’ that students must develop involves demonstrating concept mastery through measureable results or projects. This theory dovetails with Lave and Wenger’s (1998) community of practice model. The model follows the structure of apprenticeship, outlining three components: modelling, scaffolding, and coaching. Modeling involves demonstrating expertise to learners, as a guide for expert-like thinking and action. Scaffolding involves “gradual withdrawal of teacher from the process…” so that students can learn to accomplish cognitive challenges (Dennen & Burner, 2008, p. 814). Coaching involves instructor monitor and feedback of student thinking and work. “This approach has … been found to be effective in helping students learn effective problem-solving heuristics and developing their reasoning and metacognitive skills” (Marshman & Singh, 2015, p. 20). It should be noted that Singh and Marshman (2015) used the terms modeling, coaching/scaffolding, and weaning. While the vocabulary is slightly different than Dennen & Burner’s work, the fundamental ideas are parallel, and a common vocabulary for describing this construct is still not settled.

Cognitive Science

Cognitive psychology has provided contributions towards a brain-based education theory, as understanding of cognitive science grows. Zull (2006) describes four pillars of brain-based learning: Gathering Data, Reflection, Creating, and Testing. These pillars
parallel Kolb’s four cycles, providing a triangulation effect to these theories of the learning process (Appendix F). Zull is careful to explicitly point out the need for an active approach to each of these pillars: The brain does not grow independent of activity. For example, testing or validating knowledge is critical to cognitive growth—theory must be tested by action to complete learning. The field of brain-based learning is too wide and changing to fully include in this literature review, but several key aspects are noteworthy. First, emotional engagement can be a powerful tool in cognitive engagement: “Emotion is the foundation of learning” (Zull, 2006, p. 7). While cognitive activity is often perceived as a non-emotional experience, emotions (such as curiosity, frustration, or stress) deeply influence the learning process. Research suggests students generally respond with positive affect to active learning interventions, even if observed content mastery improvements are mixed (Caine, 1990; Pedra et al., 2015). Finally, negative student emotional response to content can actually inhibit learning (Zull, 2006).

One important aspect of the impact of emotions on learning is the level of stress. Too little stress, which is cultivated by a passive learning environment, results in low cognitive performance. Too much stress, which can be cultivated by a high-stakes or non-mastery environment, may evoke a threat response, which results in low cognitive performance. The optimal amount of stress provides pressure or challenge, without causing the negative performance associated with too much stress, in the form of anxiety or threat (Appendix G) (Caine, 1990; Clark, Nguyen, & Sweller, 2006; This American Life, 2012; Yerkes & Dodson, 1908). Two ways this is operationalized in the classroom is through group learning (where students must wrestle with concepts, but in a reduced-
risk environment) and through formative quizzes (where students must express their response to challenging questions without the danger of test failure); Both approaches are examples of active learning practices.

A second noteworthy brain-based learning concept is that physical action is significant in promoting cognitive structure. Zull’s (2006) discussion of neocortex signaling suggests that sensory and motor experiences lead to new associations, or “embedded behavior” (p. 4). Both sensory (taking something in) and motor (doing something) experiences engage with the environment and contribute to new associations—or learning. This is a reason that Caine (1990) suggests “engag[ing] the entire physiology” (p. 66). This also explains why Hake (1998) prefers hands-on activities, even if heads-on is adequate: The research supports it.

Third, increasingly complex cognition is effective in developing new neural pathways (Pang, 2010). So, by engaging the mind and body, active learning exercises demand complex cognitive processes (Caine, 1990). Some research suggests that this is a reason metacognitive exercises are so effective when combined with active learning—increased complexity of neural pathways (Pang, 2010). Even though Pang takes a social constructivist approach to knowledge, as it pertains to the ME-AT, there is no reason to believe that metacognitive modelling wouldn’t help with STEM-based knowledge construction.

Finally, cognitive pathways develop and grow in response to habitual use (Miller, 2011). So, when active exercises are used repetitively in class, they effectively build and strengthen new cognitive pathways that use personal experience to inform knowledge
construction. This may explain why some students show improved memory and comprehension years after initial active learning instruction (Pollock, 2009). And, it means regular, long-term use of active learning may provide substantially better overall cognitive improvements than short-term interventions.

**Engagement**

Many theories have provided a framework through which one can understand the student experience. Engagement is one aspect of the student experience that has a strong relationship with long-term student success (Astin, 1993). Engagement describes the way in which students participate and interact with their environment, both academic and social. Separating engagement into three components provides further granularity with which one may describe the student experience: emotion (or affect), thought (or cognition), and behavior. Fredricks (2004) provides a summary of existing literature that explores the boundaries of each of these themes. Affect describes characteristics traditionally thought of in emotional terms, such as stress, frustration, and joy. Cognition describes terms traditionally associated with the brain, such as curiosity and self-regulation. For the purpose of this study, motivation will be included in this domain. Finally, behavior describes how a person acts (e.g. attendance, bullying, or studying). In summary, the idea of engagement provides a simple, clear, theoretically sound framework to understand student response to their environment.
Constructivism and Cognitive Science

The common lineage of these theories—and the heritage of modern Western education—is constructivism, as defined by the theory that learners build meaning and knowledge from experience (Kurfiss, 1988). While Rousseau’s *Emile* (1817) suggested this idea around the time of the French revolution, and Piaget (1955) is often associated with the concept, John Dewey (1903, 1916) provides coherent and exhaustive thought on its implications for American education. Specifically, Dewey (1903) believed knowledge was constructed from personal experience and connection. Hence, education was the process of building personal knowledge through exploration of the natural world (Cahn, 2011). Extensive research, especially over the past 30 years in the field of cognitive psychology, has demonstrated that constructivist approaches to education promote greater conceptual mastery, complex cognitive skills, academic success, self-regulation, and meta-cognitive skills (Pang, 2010; Prince, 2004).

The constructivist model led to a revolution in education, known as the open-education movement. This shift in education was so-named because the student’s opportunities were open to him, rather than dictated and confined. While the ubiquitous nature of active learning in constructivist theories is clear, several critiques and limitations to active exercises remain. While a reading of Rousseau’s *Emile* might fill the modern reader with contempt for the laughable naivety of the story, the work provides a glimpse into the thoughts and struggles of late-18th century philosophers and educators. Early critics of the open-education movement, such as Egan, lambasted the idea that a young, petulant child should be encouraged to explore his own reality (Cahn, 2011).
First, while fresh and relevant, the impulses of youth are capricious and temporary: How do educators address the impulses of youth? Second, Dewey (1903) promoted education occurring at the intersection of experience and curiosity / new ideas, where the student would be free to explore nature in all its wonder. Yet, how can a student possibly exercise foresight that is accessible only to her older self? Egan asks how our self-directed student learns about the Italian Renaissance (Cahn, 2011). Or the Scientific Method? This raises serious questions, such as “What model enables educators to sculpt a curriculum to meet a student’s true needs?” While Dewey’s suggestion that learning occurs at the intersection of experience and ideas, how does a school guide that experience to create a well-rounded, thoughtful scholar, not subject to the whims of “any Utopian fad…” (Cahn, 2011, p. 385)?

Egan is effective in his critique of open education: It lacks structure, it exposes students to threats from without, and it is reactionary (Cahn, 2011; Dewey, 1938). While Egan’s response was surely valid criticism for many early twentieth century schools that were uncritically implementing the newest education fad, the argument lacks teeth in the light of Dewey’s (1938) *Experience and Education*. Dewey is careful to highlight the way in which educators guide the student’s growth. The educator is a liberal scholar who understands the path that the student is tracing and is hence able to guide and support the student on their path. In other words, just because a student must create their own experience does not mean they cannot (or should not) be guided. In fact, he discusses, at length, the factors in curriculum design, necessarily assuming the centrality of discipline
and focus in continued growth: Curriculum is a map to guide and facilitate, rather than a substitute for personal experience (Dewey, 1903).

Active Learning

Active learning has been the topic of broad discussion as the popularity of progressive practices took hold in American education. Per Chapter 1, the functional definition for this research is “An approach that uses exercises, in which students participate, during learning,” though multiple definitions exist (Prince, 2004). This section will address several key aspects of active learning that are relevant to this research. First, I will look at the literature regarding motivation, given the central position in student growth held by motivation. Second, the influence of active learning in redefining the teacher’s role will be explored. Third, the relationship between active approaches and concept understanding will be examined, followed by development of higher-order thinking, and growth as an expert. Next, various ways in which active learning is operationalized will be discussed: Simulations, Formative assessments, Multimedia, and the Science Education Initiative (SEI) framework. Finally, I will address opposition to active learning, followed by limitations regarding their implementation.

Motivation

According to Dweck’s (1986) motivation theory, motivation is a core aspect of a student’s growth during their education experience. Learning-goal orientation leads to stronger focus on knowledge construction, personal engagement with the learning
experience, and resilience in the face of challenges (Dweck, 1986). Active learning has been shown to promote motivation and cultivate an inquisitive approach to knowledge construction (Pedra et al., 2015).

In Pang’s (2010) study of metacognitive activities in the social sciences, she found that active learning approaches promoted motivation and develop “…strong cognitive abilities and academic skills” significantly more effectively: “In designing learning based on an active, constructivist approach, professors elevate levels of understanding, generate self-confidence and motivation, among other psychological constructs, and promote deeper learning” (p. 32). While her metacognitive model is based on social science research, such as criminal law, the argument she makes for the contribution of active learning to motivation is equally applicable in technical fields, such as physics. She cited research that found inquisitive responses to a problem-based learning approach, which indicated learning-goal motivation, positively impacted retention and ability to apply knowledge. She then suggested that the increased motivation from active learning leads to both more advanced and complex thinking patterns (Pang, 2010). Dweck (1986) herself noted similar findings, in research that indicates intrinsically motivated students perform better academically, especially in the face of challenge.

Because of the passive classroom environment’s inherent influence on motivation, Dewey’s (1938) Experience and Education presents a scathing argument directly against the passive lecture model: Passive environments put “seeming before being,” as pupils are expected to exhibit “artificial uniformity” (pp. 39-42). It should be noted that Dewey
(1903) sees education as no collection of mere facts or skills, but a deep and expansive cultivation of the self, through engagement with, and reflection about the world that one has experienced. This offers insight into Dweck’s motivation principles. A passive environment encourages and trains students to maintain passive behavior during knowledge acquisition, as uniform appearance of content is encouraged. Interruptions, in the form of clarifying questions, comments, or explorative questions are discouraged. Hence, practices typical of intrinsically motivated students that focus on effort, such as curiosity and clarification, are suppressed. Practices of extrinsically motivated students that focus on performance, such as the appearance of competence and focus on skills that are covered in class, are rewarded. As a result, passive learning environments facilitate growth of maladaptive orientations.

Situated learning theory furthermore adds to these critiques of passive learning, in terms of motivation theory. The COP model suggests that *didactic caretakers*, or those in control of the teaching environment, traditionally define project expectations and direction on LPPs in college; This is the typical model seen by existing undergraduates throughout their education. As a result, learning expectations are projected upon students, and identity development is largely artificial. A second result is that learning is equated with meeting external requirements, such as good grades. This external motivation contrasts with intrinsic motivations in two ways. First, students see the grade received as the value, as opposed to the knowledge gained to be used. Second, students focus on minimum knowledge required, as opposed to the cutting-edge knowledge required for participation in the community. It should be noted that this characterization
of COP interpretation of the existing university culture is not reflective of some inherent
ontology of academia, but rather of how society has chosen it to be (Cox, 2005).

Redefining Teacher Role

The integration of active practices in the classroom are not consistent with
traditional interpretations of the teacher’s role as lecturer in the classroom, which are
often passive; Passive environments and lecturing go hand-in-hand in a traditional
setting. In other words, if the lecture leads to maladaptive practices that favor appearance
over competence, how does a teacher lead a class? One might inquire, “What is the role
of the teacher in an active environment?” Kurfiss (1988) provides a clear, instructive
description of an instructor’s role in healthy student growth, when describing the
intervention phase of Karplus’s operationalization of Piaget’s theories: “When the
instructor sees that [the students] are ready to crystallize these [active] discoveries, the
process shifts from exploration to identification of the observations, principles, rules, or
other regularities which the students have found.” (brackets mine) (p. 147). Here, it is
incumbent on the instructor to assess the status of the student before guiding him to the
next step. There is always need for expert response and guidance while learning new
concepts: They guide thought. Yet, while an expert’s guidance is valuable for student
exploration of concepts or in one-on-one interaction, lecturing achieves neither of these
goals.

This argument is reflective of Dewey’s (1903) proposal that the child and the
curriculum are two ends of a continuum: The child explores relationships and the
curriculum explores ideas. Exploration of relationships or ideas is active, and it needs
guidance, cultivation, and discipline, from a seasoned instructor, to develop the student’s full growth (Dewey, 1903). In fact, some suggest that an active environment provides a great teacher with opportunities to offer insight and to model clear thought, rather than relegating them to the role of content presenter (Khan, 2012b). While a teacher’s role is to support and guide, a passive lecture leaves little room for these skills; the teacher has been replaced by a presenter. Moreover, the students’ peers have been replaced by an audience. Simply explaining ideas, characteristic of passive lectures, provides no opportunity for personal struggle with new ideas, nor expert feedback on knowledge construction. In summary, the role of the instructor is to support, guide, and facilitate the learner through all stages of growth. It should be noted, however, that nowhere does growth happen with the simple requirement of ‘showing up’—growth requires engagement, either internal or external. This brings up another argument for active learning exercises—that of productive resource allocation. The lecture model brings a learner into an environment with engaged peers and an interested expert. Rather than leveraging these resources to build high quality experiences and peer discussion about interpretation of the experiences, passive lectures simply tell learners about the world around them. While lecture environments may have once been the most effective venue through which to transfer knowledge to large groups of people, the tools available to educators have progressed through the years—as well as the types of knowledge that is expected. Modern resources include a large literate population, widely available laboratory and demonstration equipment, to say nothing of the vast multimedia content available through the internet (or the chalkboard) (Richard E. Mayer, 2005; Wesch,
2007). Even Lowman (1996), who makes a compelling case for the profound influence an instructor can make on student success in his chapter *What Constitutes Masterful Teaching*, concedes that passive lectures waste resources: “…designing class sessions primarily to transfer information wastes precious time as well as opportunities for more complex learning” (p. 204).

Another inefficiency in the knowledge transfer model of lectures pertains to community. The classroom is an environment full of learning opportunity in the form of peer engagement. Many studies have demonstrated the value of collaborative and group-based learning in active environments (Berry Jr, 1991; Hake, 1998; Mazur, 1999; Roehling, Kooi, Dykema, Quisenberry, & Vandlen, 2010). Treating students only as audience members loses opportunities for growth through peer-based activities. In summary, taking an environment with engaged peers and an interested expert to simply receive information is a tragic waste of resources in the modern era (Khan, 2012a; Warren, 1997).

**Enhances Learning**

Constructivist theory suggests that active approaches facilitate personal experience, and knowledge is built on personal experience: “What comes to us from our experience… is … education” (Cahn, 2011, p. 163). According to a constructivist reading of the Kolb model, the higher the quality of the experience, the higher the quality of the reflection, the higher the concept mastery, and the higher the application of new knowledge. In fact, while active environments influence student motivation, much of its value to the STEM community relates to improved learning, often in the form of
increased content mastery. For example, most physics education research focuses on improving and understanding learning improvements (Prince, 2004). Other aspects of learning that are important to the STEM community are memory, complex thinking, and avoidance of misconceptions (Freeman et al., 2014; Goldhaber et al., 2009; Hake, 1998; Mazur, 1999; Pollock, 2009).

Piaget’s theory also promoted active learning; Engagement with the natural world maintains tension between internal structures and external realities. In other words, active exercises highlight tensions between Piaget’s assimilation (redefining experience interpretation to match existing internal structure) and accommodation (redefining internal structure to align with new experience), as students struggle to reconcile their own epistemology with their new experiences. Piaget proposed a model of learning where there is a challenge that is at the limits of the learner’s existing capability (that can only be achieved by reconciling difference between the learner’s existing knowledge state and new experiences from her education): optimal mismatch (similar to Vygotsky’s Zone of Proximal Development or Posner’s Conceptual Change). Wherever this optimal mismatch occurs, PER suggests that the learner needs “appropriate guidance and feedback for the ‘assimilation and accommodation’ of new ideas consistent with classical physical laws” (Marshman & Singh, 2015, p. 20). It should be noted that the starting point for guidance and feedback is physical engagement with the phenomenon under study, through simulation or other active exercise. Finally, it should be noted that Piagetian programs are rated the fourth most effective education intervention (out of 195) by the Hattie index, with an impressive effect size of 1.28. And, while Piagetian
Program meta-analysis applies mostly at the elementary school level, the movement from concrete to abstract concepts may be seen in all levels of learning (Hattie, 2015).

Building on the Piaget’s promotion of tension, confusion is one characteristic of student experience that comes from student navigation of the Zone of Proximal Development, and some research has identified this feature in physics content. Mazur’s (1999) work on peer instruction found that the confusion (stemming from student discussion with their peers about new concepts, as opposed to stemming from unclear presentation) was initially challenging, but resulted in improved growth: “We find that student expressions of confusion are negatively related to initial performance, confidence in reasoning and self-efficacy, but positively related to final performance when all factors are considered simultaneously” (p. 20). This reflects the difficulty of learning well, the difference between initial understanding and long-term mastery, and the role that active exercises play in the process. However, Mazur’s research focus is mainly physics content knowledge, within the context of a predominantly lecture-based model, interspersed with clicker-enabled response questions that integrate peer discussion. So, these insights do not explore other components of the student experience, and they are based on limited active interventions.

In The Child and the Curriculum, Dewey (1903) proposes a subtle argument opposing the practice of passive lectures, that provides a glimpse into the value of learner-centered approaches. Dewey highlights the importance of intellectual freedom in personal growth. Passive lectures impose external restrictions on the inherent curiosity of a child, and the inherent right of intellectual freedom, in two ways. First, lectures
artificially pace coverage of the material in a way that will either suppress the growth of
some or inhibit the comprehension of others. Second, by limiting the scope of the
curriculum, the freedoms of the learner to inquire and explore are restricted (Dewey,
1903). Active learning, during either exploration or structured testing, enables
intellectual freedom, which is an essential component of maturity of the learner.

While constructivism suggests a number of strengths for the learner, the idea that
it cultivates innovative ideas is especially pertinent to physics education. One only need
read a cursory review of the most recent NSF RFPs to see that there are substantial
incentives for creative application of knowledge. Dewey (1916) suggests that novelty
and creativity (that characterize brilliant ideas) is not in the ability to know ideas, but in
the ability to connect ideas. He cites Newton’s conception of gravity as predominantly
coming from a new way to look at things, rather than in incremental difficult steps. This
suggests a high value of cultivating students to create their own meaning. In fact, this is
an idea that Dewey later develops as critical to educational growth (Cahn, 2011, pp. 314-
315; Dewey, 1916, 2004). Of particular interest to STEM fields is the immeasurable
value of innovative thought that characterize almost every technical breakthrough. For
example, quantum mechanics is a field in dire need of new insight, given the inexplicable
and unintuitive characteristics of existing interpretations of quantum theory (e.g. coupled
states, entanglement, and spooky action).

An essential component of learning, according to any model, is that of reflection.
Grossman (2008) identifies four types of reflection: content-based, metacognitive, self-
authorship, and transformative. While there are some aspects of metacognitive reflection
vocabulary in PER literature (such as self-regulation), it is usually used solely to ensure accuracy of content knowledge. Within STEM education, *content-based* reflection is predominantly the focus. While the difficulty of deep reflection in an active environment is a valid concern, one must remember that the classroom environment is one aspect of the entire learning experience. The quiet reflection necessary for deep learning and conceptual wrestling is best experienced in an environment free of distraction and time constraints—certainly not within the confines of a classroom. This is true for both active and passive classroom environments. Singh and Marshman (2015), in their exploration of student difficulties in quantum, argue that “Reflection and sense-making are integral components of expert behavior” (p. 19). The central question is how effectively the classroom environment contributes to progression through the Kolb cycle. A passive environment ‘tells’ about an experience, or worse-tells what learners ought to gain from an experience (i.e. how might one interpret the phases of Venus?). An active environment, on the other hand, provides learners with a personal experience, as well as the opportunity to interpret that experience with their peers. It is worth noting that Singh and Marshman (2015) go on to say that “Experts monitor their own learning. They use problem solving as an opportunity for learning, extending, and organizing their knowledge” (p. 19). In both passive and active environments, reflection about underlying concepts is an equally necessary part of Kolb’s cycle: the distinction is in the inherent quality of the experience upon which they are reflecting. Providing active exercises enables learners to have personal experiences and peer engagement during the respective parts of the Kolb cycle, where they may test their ideas and where community is an
essential component to learning. In this type of structure, they are developing expert-like behavior: monitoring their learning in community, testing their ideas with activities, and extending their knowledge through play with active exercises.

Finally, the literature in the physics education field presents a variety of ways in which active environments enhance learning (Prince, 2004). Active learning helps with long-term growth in complex concepts (Deslauriers & Wieman, 2011; Pollock, 2009). Active learning improves conceptual understanding of essential content (S. V. Chasteen et al., 2012; Hake, 1998). Active learning cultivates better metacognition (S. V. Chasteen et al., 2015). In summary, both constructivist theory and measureable outcomes agree that active environments enhance various aspects of learning.

Higher-Order Skills

One aspect of learning absent from the previous section is higher-order skills or complex thinking patterns. This topic is important enough that it merits its own section: College graduates with technical degrees are expected to not only know core content, but how to use more complex thought patterns to solve problems: developing these patterns takes practice in creativity, analysis, and manipulation—typical active learning exercises (van Gelder, 2005).

Dewey (1903) clearly addresses the role of active learning by suggesting that the learner-centered and curriculum-centered models are ends of a continuum, where the common thread between the endpoints is the best approach for a learner’s development, as defined by “freeing the life-process for its own most adequate fulfillment” (p. 281). He later clarifies that it is the “experience[e] that [is] worthwhile educationally…” that
the learner needs to meet this goal (1938, p. 18). While much of his discussion falls outside the scope of active learning, several ideas are worth mentioning. Dewey coined the term *psychologize* to describe the act of the learner in confronting, digesting and understanding subject-matter within the context of personal experience. This digestion is an inherently heads-on activity (at least) that builds new relationships. Also, Dewey (1938) suggested that knowledge only has “significance” when an education provides “immediate and individual experience[e],” directly asserting active learning as a fundamental component of a growing intellect (p. 44). Finally, he contrasts active and passive learning, establishing the relative merit of active environments.

Active learning can also change the type of approach one takes to knowledge. Pang, (2010) while researching metacognitive traits, suggests that “active learning…emphasiz[es] an inductive methodology where there is learner experimentation and knowledge construction” (p. 30). Dewey (1903) writes that personal experience characterizes the continuum between child and curriculum—the learner must own the progress. The value of curriculum (focus and discipline) is that it makes sense of personal experience in a focused, structured way. The personal experience may be structural modelling of physical experience, through simulations, math, or mental constructs—but the learner herself must construct all her knowledge. While a teacher can show concepts, the learner must experience it, often through inductive logic in STEM. A passive worldview puts the burden of responsibility outside of the power of the learner—they’ve lost control. Active exercises, of all sorts, continually re-orient the burden of the work, power, thought, and responsibility back on the learner. This may look different at
varying stages of education (K to 16), but the learner-centered (and supported)
experience is central (Dewey, 1903, 1916, 1938).

In contrast, most STEM studies focus on conceptual mastery and problem-solving
skills, rather than more advanced cognitive skills, such as creativity or evaluation, so it is
not clear what effects active learning might have on these skills within STEM (S. V.
Chasteen et al., 2015). There is an irony to this gap, as some suggest that active learning
environments cultivate more advanced thinking patterns, which are especially valuable in
STEM fields (Khan, 2012b; Pedra et al., 2015). If the broader community is neither
assessing nor instructing students in pursuing these more complex thinking patterns, it
should be no surprise that the literature is silent about the effects of active learning on
these types of cognition.

**Becoming an Expert**

An essential component of professional success, in industry or in academia, is
being—and becoming—an expert. This aspect student growth relates to active learning,
when viewed through the lens of a Community of Practice. The COP model has an
interesting relationship with active learning, as the Legitimate Peripheral Participant
(LPP) construct encompasses learners that take both passive and active approaches to
knowledge growth. In fact, Wenger (1998) suggests that a necessary component of the
COP is learner choice to remain passive: non-participation is essential to identity
formation. Because of the community’s benign neglect, the only path to success is
through participants taking responsibility for their own growth (Lave & Wenger, 1991;
Wenger, 1998). The COP model proposes that only those learners who engage like a
member (and recognized by the community for doing such) may move deeper into the community: Content-specific mastery is a necessary but insufficient criterion for community recognition. In other words, novices who are able to engage their expertise with the broader community can achieve recognition as active members. For clarification, Lave and Wenger argue that the engagement with the community and the learning are the same act. As previously noted in the discussion of Kolb’s Experiential Learning Cycle, innovation or generation of knowledge is inherently an active experience. Since core membership in the COP requires demonstration of expertise (most likely in innovative ways), core members are characterized by both active approaches to knowledge growth and more complex thought patterns; that is, higher levels of Bloom’s taxonomy. This suggests that at least the most advanced practitioners have integrated active practices in their growth as experts.

The COP model has profound implications for education. The experts at the center of the community are professors and professional researchers, while the core members include graduate students and undergraduate researchers. Those students who use their knowledge to contribute to larger projects have moved from LPP to more central figures in the community. These students have taken a more active role in knowledge construction—they are engaging their knowledge with the world around them, rather than isolating their cognitive perceptions from the physical world (Lave & Wenger, 1991).

In summary, situated learning integrates two aspects of active learning. First, situated learning suggests that engagement with the broader society is a necessary component to cognitive growth. This aspect promotes active learning, through communal
engagement, as a necessary component to education. Moreover, situated learning suggests that social engagement is a characteristic of expert-like behavior. Second, the COP model suggests that the path to professional recognition and success is through recognized expertise and contribution to the field. The second aspect promotes active behavior (or initiative), through novel knowledge generation and engagement with other members. One can interpret these as two sides of the same coin: the first aspect reflects active learning, and the second aspect reflects active educating. It is not difficult to imagine that students who have been immersed in active environments would naturally succeed within a COP framework.

Singh and Marshman (2015) explored challenges in both introductory mechanics and quantum mechanics using the related framework of cognitive apprenticeship. They found that weaknesses in student cognitive development could be understood using this framework, for both lower- and upper-level content areas. For example, lectures seldom provide the explicit modeling necessary for students, even though it is possible through teacher training. However, coaching and scaffolding require much more student engagement, mainly by creating cognitive conflict. This relates to Piaget’s Optimal Mismatch and Vygotsky’s Zone of Proximal Development, where active learning exercises provide the necessary source of tension for learners to develop new understanding.

What is truly lacking in the traditional instructional approach is coaching and scaffolding. In that sense, the traditional model of teaching physics is akin to asking students to watch the instructor or the TA play piano (solve physics problems for them) and then telling them to practice playing piano on their own (solve physics problems in homework) (Marshman & Singh, 2015, p. 20).
Singh and Marshman (2015) suggest using progressive scaffolding tools that help students develop a functional knowledge, “…such as tutorials, peer instruction, group problem solving, and exploiting computers for pedagogical purposes, e.g., the ‘just-in-time teaching method’” (pp. 20-21). They argue that active learning exercises would help diagnose errors, make sense of content, discern anomalies, and understand multiple perspectives. Effective active learning exercises should invoke disequilibrium between existing (incorrect) models and experienced phenomena, as well as provide expert feedback, according to this model. By focusing on scaffolding and coaching in course curriculum, their research suggests the apparent weaknesses in existing student cognitive abilities would be addressed. However, the researchers failed to use this opportunity to explore the relationship of motivation, complex cognitive skills, or other expertise within the cognitive apprenticeship model.

**Progressive Practices**

Thus far, I’ve explored several critical characteristics of active learning in the STEM classroom that are rooted in constructivist education theory and are substantiated by literature in STEM and cognitive science. Active learning has been shown to support adaptive frameworks consistent with internal motivation. Active environments allow the teacher to support student growth more effectively as they move out of the lecturer role. Active learning supports higher-order cognitive skills, and it is consistent with existing models that promote becoming a recognized expert.

However, one might still wonder what active learning looks like. How is it operationalized? What does theory and research say about active techniques? Which
exercises should an upper-level quantum mechanics course use? While these are often contentious questions that largely fall outside the scope of this literature review, a brief exploration of significant activities that have seen widespread use in STEM is in order.

**Simulations.** One of the most useful active exercises for upper-level physics content is simulations. Because the phenomenon under study is seldom—if ever—observed directly in daily life, it is essential for students to experience the physical phenomenon in some other way. Computer simulations provide an accessible, accurate, and manipulative avenue to explore these elusive physical laws. To create accessible personal experiences, the field of physics education has inspired a number of web-based resources for experiencing quantum mechanics models, such as PhET simulations (McKagan et al., 2008), QUILT tutorials (Singh, 2005; Singh, Belloni, & Christian, 2006, p. 47), and open-source Quantum curriculum (S. V. Chasteen et al., 2015). The Physics Education Technology (PhET) project now includes 18 quantum mechanics simulations that model a number of simple and complex quantum phenomenon (McKagan et al., 2008). QUILT tutorials have been developed to connect abstract understanding to physical phenomenon(Singh et al., 2006). These tools provide avenues for personally exploring physics phenomena, which may provide a solid foundation upon which a student may build conceptual knowledge. Research quantifying this effect has supported this idea (Meltzer & Thornton, 2012; Pedra et al., 2015). These types of resources are especially important for content that is not readily observed in daily life, like relativity and quantum mechanics. In fact, a number of these resources were used during the transformation of the course researched in this study.
Formative Assessments. A second widely-used active practice is formative assessments. Formative assessments provide an avenue for testing comprehension, and re-educating before proceeding. Bloom (1968) postulates this “pace[s] the learning of students and help[s] motivate them to put forth the necessary effort at the appropriate time” (p. 9). He also indicates its practical utility: “If we are able to develop mastery… in students, we must be able to recognize when students have achieved it” (B. Bloom, 1968, p. 8). The Hattie index reports an intervention effect of +0.68 for providing formative evaluations, and +0.52 for frequent assessment, well above the cutoff of +0.40 (Hattie, 2016). Kulik, Kulik, & Bangert-Drowns (1990) reported +0.59 for studies that included frequent formative assessments (p. 287). Including the results from retests, as reported by Guskey, yielded an effect size of +1.17 (Guskey, 1985; Kulik et al., 1990, p. 287). This may indicate that summative assessment does not capture all the advantage that formative feedback provides. Summative results may be compromised by long-term memory degradation, an aspect of learning which active learning does not explicitly address. Others conjecture that increased assessment quantity may give students more practice with necessary knowledge and reasoning, thereby more effectively preparing them for summative evaluations (Semb, Ellis, & Araujo, 1993). In other words, the net positive effect may be nothing more than a pithy saying: Practice makes perfect. However, it is substantial nonetheless.

In addition, formative assessments provide a feedback mechanism between instructor and student. As noted previously, feedback is essential for guiding students on their next steps, and it is a critical component to active learning. Who has attained
mastery? Where are students struggling? Through feedback, students can identify weaknesses in their understanding, and educators are able to guide students on the next steps that they need to take to accomplish mastery. This reflexive process may be one of the most influential sources of the formative learning effect. In fact, formative assessments, in the form of i-clicker questions, is one of two critical in-class components of the dominant active learning model in upper-level physics, the other being peer collaboration (Goldhaber et al., 2009; Integrating Cognitive Science with Innovative Teaching in STEM Disciplines, 2014).

It is worth noting that a critical component of formative assessments is timely feedback. Bloom (1968) suggested that frequent pass-fail assessments, that did not count towards a grade, and were quickly followed by diagnostic feedback for the student, were most useful for student learning. Guskey (1985) states that “the most essential element in the mastery-learning model is the feedback and corrective procedures” (p. 131). Feedback interventions (+0.73), and, to a less-direct extent, individualized instruction intervention (+0.23) indicate net positive influence due to frequent, timely feedback (Hattie, 2016).

**Multimedia.** Because the active classroom requires higher student engagement and contribution to class discussion, student preparation for class has increased importance for the entire class. Good class preparation benefits the students’ peers, as well as themselves, in an environment that depends on peer discussion. One of the most effective techniques for learning elementary concepts is multimedia (R. E. Mayer, 2002). In addition, participation is easily tracked through modern learning management
Moreover, increased variety in cognitive exercises facilitate cognitive growth; this concept aligns with the central argument for learning styles, as first proposed by Felder and Silverman (1988).

Richard Mayer (2002) has done extensive work on clarifying characteristics of effective multimedia resources, through his work in *Cognitive Theory of Multimedia Learning* (CTML). CTML theory is based on three research-based assumptions:

1. The dual channel assumption. “Humans possess separate channels for processing visual and auditory information.”
2. The limited capacity assumption. “Humans are limited in the amount of material they can process in each channel at one time.”
3. The active processing assumption. “Humans engage in active learning by attending to relevant incoming material, organizing selected material into a coherent mental representation, and integrating mental representations with other knowledge.” (R. E. Mayer, 2002, p. 103)

These assumptions provide a framework under which meaningful learning can occur with the engagement of the following cognitive resources: multimedia presentation, sensory memory, working memory and long-term memory. Mayer has created a list of nine progressive, multimedia learning best-practices that align with CTML theory:

1. Multimedia- Use words and pictures rather than words
2. Spatial contiguity- Place words near pictures
3. Temporal contiguity- Narrate and animate together
4. Coherence- Use only relevant words and pictures
5. Modality- With animation, use narration rather than text
6. Redundancy- Omit duplicate presentation of content
7. Pre-training- Explain components before explaining the system
8. Signaling- Use signals on important points

These best-practices apply to many technology-based tools, which are simply multimedia resources for the 21st century. Online simulations and demonstrations allow students to visualize and manipulate physics phenomena, as well as mitigate misconception dangers (Muller & Sharma, 2007; Pedra et al., 2015). Providing pre-lecture videos on elementary concepts has been shown to improve student learning during class (Ibrahim, Callaway, & Bell, 2014; Stelzer, Gladding, Mestre, & Brookes, 2009).

*Khan-style Videos* (KSV), in particular, exhibit several progressive characteristics, when executed properly (Khan, 2012a). First, videos support knowledge- and comprehension-based learning targets. Second, using multimedia best-practices, listed above, improves student comprehension, retention, and conceptual understanding (Clark et al., 2006). Third, short videos (6-8 minutes) accommodate learner attention span (Middendorf & Kalish, 1996a). Fourth, videos should use a standardized structure based on teaching good-practices (engaging questions, for example) (Chickering & Gamson, 1987; Clark et al., 2006; R. E. Mayer, 2002; Richard E. Mayer, 2005).

In addition, research has established that segmented media (less than 10 minutes) are more effective than longer 50-minute lectures (Ibrahim et al., 2014; Johnstone & Percival, 1976). Cognitive theory (limited capacity and active processing assumptions)
suggests that the brain’s technical focus on new material has limited capacity, as subjects move knowledge from working memory to long-term memory (Ibrahim et al., 2014). While Wilson and Korn (2007) offer a critique that questions the validity of the efficacy of segmented media, their inability to provide solid evidence for the doubt they shed on individual findings, combined with the mound of evidence that they have chosen to challenge, leaves their findings unconvincing, at best.

The Science Education Initiative

One of the widest-implemented and most-researched systematic implementations of progressive practices in physics (and other STEM fields) may be found in the Science Education Initiative (SEI). SEI provides a well-tested model for transforming physics courses from traditional lecture to a more progressive environment, as it has seen widespread implementation in STEM courses (S. Chasteen & Perkins, 2014; S. V. Chasteen et al., 2015; Goldhaber et al., 2009). Deslauriers, Schelew, & Wieman (2011) implemented the SEI active learning model in an introductory physics classroom and included the following activities: preclass preparation, student-student discussion, small-group active learning tasks, and targeted in-class instructor feedback, rotating in 5-10 minute time chunks. While the study only lasted less than two weeks, conceptual mastery increased by an effect size of 2.5 (!). A later iteration added clickers, optional tutorial, optional group help sessions, and preclass assignments. Variations in class activity provide a rich environment for both active learning and accommodation of various learning styles (Felder & Silverman, 1988). Students report strong preference to this model, as opposed to the traditional lecture model. This study used the SEI model as
a template for effective implementation of active learning in the context of an intro physics class.

The operationalization of the SEI model depends on the subject matter and student demographics. The 2010 study mentioned in the opening paragraph (with an intervention effect size of 2.5) was an introductory EM Physics class, populated mostly by about 270 freshmen engineers and physicists (S. V. Chasteen et al., 2012). During the study duration, lecturing was effectively eliminated from the class, though instructor feedback did provide commentary and brief discussion of topics covered.

With the success seen in active learning in introductory classes, a modified SEI model was developed for upper-level courses. The modified model combined Hake’s (1998) Interactive Engagement and Mazur’s (1999) Peer Instruction models to adjust the traditional lecture, by introducing active exercises to promote student involvement and check conceptual understanding (Goldhaber et al., 2009). To address inherent weaknesses of the lecture model, several additional changes were made to the course structure (such as the development of a concept assessment tool (the QMAT), and a strategic approach to curriculum development, including tools like learning goals):

1. Weekly optional recitation sessions were guided by experts, where students worked through structured tutorials in small groups.
2. Homework assignments were adjusted to specifically address “reasoning, estimation, and … [mathematical] connections…”
3. “Instructor office-hours were replaced with a cooperative, weekly session where students worked in groups on the homework” (Goldhaber et al., 2009, p. 145).

In particular, advanced quantum mechanics classes largely follow a lecture-based model—the student population usually consists of a smaller group of upperclass physicists. Backward-design was used to create clicker questions, followed by peer-to-peer discussion (in which almost everyone participates voluntarily), and instructor feedback (based on the distribution of the responses) occurs throughout the class period, with 3-5 clicker questions being asked during each class (S. Chasteen & Perkins, 2014; Hake, 1998; Mazur, 1999). For example, a SEI-transformed quantum mechanics class, which the author observed, consisted of 5 clicker questions, each taking 3-4 minutes for peer discussion and instructor feedback, with 43 students present. It should be noted that both introductory and advanced models include some similar out-of-class activities, such as structured problem-based recitation sessions, and individual worksheets with completion quizzes. In fact, active learning exercises may be operationalized in a number of various ways, but with strongly correlating themes, so the SEI has categorized various aspects of a transformed class to provide a more coherent perspective of progressive interventions (and their applications) within STEM (S. Chasteen & Perkins, 2014, p. 129):

Table 1. Components of effective physics transformation

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>Literature search, classroom observations, and student interviews</td>
</tr>
<tr>
<td>Learning goals</td>
<td>Developed explicit course goals in collaboration with faculty</td>
</tr>
</tbody>
</table>
Thus, to summarize, below we list the various outcomes from the typical course transformation in the program:
• Course learning goals: Developed with faculty working group, for course as a whole and individual topics
• Student difficulties: Review literature, observe and interview students, create diagnostic tests
• Conceptual assessments: Develop research-based conceptual surveys based on learning goals to test student learning
• Improved teaching methods: Target student difficulties with instructional techniques consistent with the research on how people learn
• Archived materials: Provide materials in organized online repository
• Plan for sustainability: Establish departmental structure and plan teaching assignments to ensure ongoing use. (S. Chasteen & Perkins, 2014, p. 127)
The difference in the ways that the SEI model is operationalized highlights the importance of maintaining student feedback (Petersen & Gorman, 2014). Every learning model addresses the growth of a student, so it seems perfectly reasonable that the way a student learns grows, as well. While course designers may guess at the most effective approaches to a particular class, student feedback regarding conceptual difficulties and perceived value of different activities is essential for effective implementation of progressive techniques. Finally, a successful course transformation may take several rounds of refinement (S. V. Chasteen et al., 2011).

Opposition

**Lecture Works.** Some object that active learning may remove the teacher from the focus of the learning process (Petersen & Gorman, 2014). For example, rather than the instructor being the center of attention (hence, control), active exercises usurp classroom control from the teacher and give it to the students (Petersen & Gorman, 2014). There is some validity to this argument, as active exercises do surrender much of the control for activities to learners, at least during active exercises. However, here, one must examine the goal of the lecture. Is it meant to cover material? Or, is it meant to guide student growth? As discussed earlier, active learning allows the teacher to engage with the student as a guide and expert, rather than a lecturer. While this requires that the instructor relinquish some of the control, it empowers the instructor to be a true teacher, rather than a simple authority. Finally, in an age of broad access to quality education resources, using a highly educated expert to simply disseminate knowledge is a wasteful proposition within the context of resource allocation, as discussed previously. In
summary, active learning enables the teacher to be present to support student growth, rather than simply presenting knowledge and calling it teaching.

Some suggest a more informal and refined lecture model, where questions are fielded and concepts are thoughtfully illustrated, would address concerns about education quality; It may be that a well-run lecture is the best option (Prince, 2004). Lowman’s (1996) promotion of “…engaging examples…” suggests an acknowledgement of the strengths of an active environment: As discussed previously, constructivism maintains that personal experience is the foundation of lasting knowledge (p. 204). Active exercises, such as clicker questions, are tools for promoting informal discussion of difficult concepts. This empowers the student to construct accurate conceptual models. And, for developing more complex thinking patterns, class may be used to “…clarify especially difficult concepts or procedures… illustrate content using engaging examples, and … emphasize the connections among different concepts” (Lowman, 1996, p. 204).

In upper-level physics classes, there is some data to suggest that traditional lectures can be effective, even if they merely include simple active learning exercises, such as clickers and peer instruction (Perkins, Turpen, Sabella, Henderson, & Singh, 2009; Singh & Marshman, 2015). Yet none of these approaches provide an objective measure of student comprehension; The closest solution is clicker questions, but they generally only address simple problems with multiple choice response. In other words, how does an instructor know which topics students find most difficult? And, which students have the difficulty?

One model that is the subject of some of the most highly referenced research explores the advantages of adding clicker-based questions to the traditional lecture, as a
way to infuse lectures with some of the advantages of active exercises (Hake, 1998; Perkins et al., 2009). While the findings of his research demonstrated the benefit of improving the lecture model, Hake’s seminal work simply compared passive lectures to those with some sort of feedback mechanism or activity. While Hake does identify a number of studies that showed poor implementation of active methods that resulted in reduced student outcomes, his treatment of active best-practices is far from rigorous. For example, he only identifies rough guidelines for active practices that led to the highest gains, rather than looking more closely at specific aspects of active environments, such as time spent, levels of cognition, out-of-class work, etc. In other words, while Hake’s results indicate that superior results may be achieved through proper implementation of active practices, his results are rough, and require further research to refine the relative merits of various active learning practices.

A second model that is based on refining the lecture focuses on strategically improving lecture-based explanations of specific common conceptual difficulties (Carr & McKagan, 2009; Gire & Price, 2015; Singh & Marshman, 2015). Yet this type of approach fails for two reasons. The first reason is that this method does not allow for feedback mechanisms. While research may be able to identify prevalent misconceptions, and maybe even explanations that clearly address them (the holy grail of Computer Aided Instruction, or CAI), not all students will proceed at the same rate, or with the same depth. This leaves an instructor unable to provide support when it is needed for individual students. The second reason is similar: How well have students mastered the material? There is no feedback mechanism for student mastery or the effectiveness of
instructor explanation, as student self-efficacy and instructor perception are notoriously poor indicators of actual knowledge. Once again, a feedback mechanism—a central component of active learning exercises, but also an occasional tool in traditional approaches—is essential to effective classroom experience.

While redefining effective lecture practice is a useful endeavor, there are inherent weaknesses to the practice, in the first place. Kolb claims that gathering information is a small component of the learning cycle. Dewey suggests that personal experience is the starting point of knowledge. While clicker use may provide an opportunity for cognitive engagement and peer discussion while gathering information, the environment still insulates the learner from first-hand experience. By definition, passive approaches remove the immediacy of the experience—they lower its quality (Dewey, 1903). In addition, lectures, even with occasional Socratic dialogue (Lowman, 1984), enforce the model of student as passive recipient of knowledge, evoking the arguments covered earlier in support of active learning. Moreover, as reviewed earlier, active exercises that require student engagement have been shown to promote retention, even if those results are mixed.

Returning to Lowman’s (1996) description of a class’s purpose, do students have trouble making “connections among different concepts” simply because an expert hasn’t told them in just the right way (p. 204)? Is it really that simple? Difficult concepts require focused reflection, trial-and-error, and exploration to master: learning is hard and all stages of intellectual growth require hard work and effort (van Gelder, 2005).
Finally, adjusting the traditional lecture model with active techniques, and claiming positive student affect misses the point. A thoughtful progressive approach to pedagogy should not begin with how to assimilate new understanding of learning within a handicapped structure. Rather, one should start with an understanding of how humans learn and find ways to accommodate these processes. In other words, trying to shoe-horn in active practices in existing structures inherently puts the cart before the horse. Dewey (1903) crafts a similar argument in *The Child and the Curriculum* by suggesting that infusing a broken model with active exercises to evoke curiosity is like sugarcoating a bitter pill instead of offering real food. However, this argument is inherently progressive, which carries with certain liabilities, as discussed in Chapter 1. In other words, it may be that more traditional approaches include practices whose value is not yet fully appreciated.

*Preference Matters.* Another objection to active learning is that students report positive affect and satisfaction in response to a well-run lecture, and negative response to active interventions, which affect engagement and motivation (Lowman, 1984; Petersen & Gorman, 2014). In fact, some research has shown negative response during initial transitions to active environments, under the right conditions (Covill, 2011; Lowman, 1984; Petersen & Gorman, 2014; Shimazoe & Aldrich, 2010). Interestingly, some research has found student affective response to active learning is sometimes negative, even if cognitive response is high (Prince, 2004). While many students enjoy the change for a variety of reasons, some students resist active practices for other reasons. A quick
review of the literature shows that student responses (both positive and negative) are fairly consistent within the context of earlier education theory discussions.

There are two major weaknesses of this argument. First, passive or active-- good teaching is good teaching-- neither environment is a panacea. While monotone lectures are ubiquitous enough to be a trope (“Bueller, Bueller…”), poorly prepared active classes can be even more negatively received, largely due to their disruptive nature… (Hughes, 1999). Moreover, previous experiences of poorly designed active learning activities can strongly increase resistance to new, well-designed active learning activities. This is especially problematic because faculty have limited models for effective operationalization of active models, especially in STEM fields. To exacerbate this issue, unconventional classes invite scrutiny from students simply due to their novelty. So, a poorly executed active class is doubly (or triply) liable for decreased student affect (Shimazoe & Aldrich, 2010). In fact, effective execution of active exercises is a common theme that emerged during the interview process of this research, highlighting the importance of successful active transformations in a traditional culture. In order to ensure a successful active learning experience, Shimazoe & Aldrich (2010) suggest a number of classroom best practices for a cooperative learning environment, including a proactive structured approach that adjusts to student feedback. SEI has developed a manual (with extensive resources) to guide faculty, departments, and institutions through this challenging process.

The second weakness of student preference for the passive lecture is elucidated by John Dewey (1903): “Familiarity breeds contempt, but it also breeds something like
Because of the dominance of the passive lecture model, students have grown accustomed to navigating it. Hence, active exercises can feel like an uncomfortable disruption to their education—especially since active learning requires more effort and engagement from students. Moreover, the danger exists that students have so long existed in a state of passive receipt and regurgitation, that their curiosity has been traded for conformance. In this state, active learning has little to offer such a student, and Dewey’s three evils of science have been realized: knowledge is symbolic, motivation is absent, and knowledge lacks depth (Dewey, 1903).

Finally, exploration of the impact of student learning styles fell outside the bounds of this research, though a quick note is in order. The most popular and thoroughly-explored models of learning styles is Felder’s Index of Learning Styles, which identifies learning style differences based on the Meyers-Briggs Type Indicator (MBTI) (R. M. Felder, 2010). While Bloom (1968) did suggest that “the problem of developing a strategy for … learning is one of determining how individual differences in learners can be related to the learning and teaching process,” the precise way in which student learning styles is relevant has not been reliably shown (p. 1). Even now, there are no clear consensus surrounding the way in which student learning styles influence education (R. M. Felder, Felder, G.N. and Dietz, E.J., 2002; Riener & Willingham, 2010) (Lenehan, Dunn, Ingham, Signer, & Murray, 1994).

Learning style practitioners often focus on student preference towards one style or the other, when the best presentation models use both. The learning style fallacy is something like saying we have a hopping preference of left- or right-footed, rather than
telling people to simply walk with both feet. Worst, students may come to believe that they can only hop on their left foot, when they are finally shown how to walk (Riener & Willingham, 2010). While specific theories may be challenged, no credible source would say students do not differ in learning preference in some capacity (Pashler, McDaniel, Rohrer, & Bjork, 2008; Riener & Willingham, 2010). And, Felder (2010) claims people have preference with the intent of promoting multiple classroom presentation venues, reflecting good classroom practice: “Respects diverse talents and ways of learning” (Chickering & Gamson, 1987), rather than the intent of categorizing individual students as auditory or tactile learners, as learning styles are sometimes mistakenly interpreted (R. M. Felder, 2010).

One particularly relevant weakness of the learning style construct is the promotion of visual and verbal learners, as distinct from other learning types. Mayer’s (2002) work in *Cognitive Theory of Multimedia Learning* (CTML) has found that an overwhelming majority of students learn best through effective implementation of multimedia. His theory maintains that students have parallel channels for visual and auditory input. By syncing these channels, they can work together to enable students to understand technical concepts at deep levels (R. E. Mayer, 2002).

In summary, student affective resistance to active learning exercises is largely due to student expectation and experience, rather than ineffectiveness. In fact, the clear majority of research in active learning has found that it improves conceptual mastery and student satisfaction (Covill, 2011; Petersen & Gorman, 2014; Prince, 2004; Shimazoe & Aldrich, 2010). For example, a study of outcomes of multiple upper division courses
contrasted traditional lectures with those implementing regular clicker and peer-
discussion activities (with 93% of preferences being for clicker use instead of traditional approaches) (Perkins, 2009). So, while preference for traditional models lack theoretical or empirical justification, it is still a valid and observed response for some students. Hence, it is incumbent upon instructors to support these students during transitions to active environments.

Faculty Resistance. One of the most influential sources of resistance to active learning implementation is faculty reluctance (S. Chasteen & Perkins, 2014). Four major reasons exist for this reluctance. First, faculty are reluctant to implement new pedagogies in the classroom. This is especially true when the practices have never been seen, let alone modelled for them in their personal experience. Second, extensive resources are required to transform class material, both in time and expertise. Moreover, once a course is transformed, it requires an effective teaching community to work together to continue and improve the transformed curriculum (S. Chasteen & Perkins, 2014). Third, active exercises, by definition, remove some aspects of instructor control over the pace and focus of class time. PowerPoint presentations are far easier to control and execute than engagement with a dynamic class. Fourth, developing a new approach to an existing course requires a time commitment. This is often answered by noting that instructor time commitment is generally thought of to be fairly equivalent to development of a traditional model, if transformed material is provided (S. V. Chasteen et al., 2015). However, this opposition misses part of the picture. The uncertainty about the time required to both develop material and navigate new resources will result in increased time on all tasks.
And, if an instructor has already developed the traditional model, they might perceive that time as lost. This might be especially true if course transformation is not part of a department-wide initiative: Why should an instructor develop another course (in addition to their existing workload), when it is not expected (or supported)? The SEI model suggests departmental support for transformed classes greatly improve success, as measured by thoroughness of implementation, longevity, and effectiveness for student learning (S. Chasteen & Perkins, 2014). These four reasons are worth honestly understanding and addressing, especially as institutional focus shifts to improved pedagogy in STEM.

Limitations

Exploration of various constructivist theories and cognitive science have provided a justification for why active learning may be an effective approach to education. Research that has looked at various learning outcomes has demonstrated that active approaches are demonstrably superior in concept mastery, critical thinking, motivation, and other measures. Objections to active learning that have been discussed in this paper seem to be either lack clarity regarding the role of active practices or focus on the limitations of active learning. Here, I would like to examine the evidence describing the boundaries of active learning. In other words, if it is not a panacea, one must ask, “Where is an active environment actually not beneficial?” Or, “Where is it actually detrimental?” For example, there is evidence to suggest that active learning has limited direct benefit to memory, computation-based skills, and reflection. And, active learning may not help computation-based skills. This section will address these topics.
Retention. Research has shown varied effects of active learning on long-term memory, even if it seems to improve conceptual understanding. Deslauriers and Wieman (2011) explored retention of quantum concepts (introduced in a modern physics survey course) 6 and 18 months after traditional and transformed instruction. They found similar retention between pedagogies. On the other hand, some research has found improved retention due to active learning (Meltzer & Thornton, 2012; Prince, 2004). However, none of these studies explored the long-term effects of active learning on upper-level content, which may have unique characteristics. Some suggest that unique aspects of quantum mechanics may strongly influence retention, as there are minimal real-world connections with the content (Deslauriers & Wieman, 2011). For example, improved mastery in classical mechanics, due to active learning, may be reinforced regularly through other coursework or observation of the world around us, influencing long-term memory. However, these types of ‘triggers’ do not exist for quantum mechanics, so memory may be very different between upper-level and introductory classes. It should be noted that one study evaluated long-term retention of upper-level physics majors as a function of active learning practices, however the material evaluated was introductory EM content (Pollock, 2009). In order to evaluate the effects of active learning memory influence on upper-level students, measures would have to be taken from physics graduate students.

While the relatively weak retention of physics concepts may be initially troubling, especially if one would hope exiting students could demonstrate mastery of material pertinent to their major, it is not necessarily surprising. Given the compartmentalized
nature of STEM curriculum, students seldom have the opportunity to review and practice earlier learned skills. If systematic support for inscribing topic-based concepts in long-term memory is not provided, there seems to be little reason to expect student retention of concepts to remain through graduation, regardless of instructional technique (Semb et al., 1993). This may also explain some aspects of graduate student underperformance of faculty expectation: they’ve forgotten the material (Carr & McKagan, 2009).

**Computational Skill.** Research has shown minimal effects of active learning on computational skills: Analysis of transformed classes in electromagnetics show that active learning approaches develop better conceptual understanding (CUE scores), but do not influence computation-based skills (class exams) (S. V. Chasteen et al., 2012). However, computation skills are essential components of learning, especially from a cognitive apprenticeship framework. It may be that practice is an essential component to sharpening application-based skills, such as utilizing boundary conditions in identifying integral limits, or solving eigenvalue problems {Miller, 2011 #30}. In these situations, skills practiced are less dependent on an individual experience—they are based on hours of practice.

**Stage of Learning.** While active exercises may not be appropriate for all aspects of learning, constructivist theories suggest that personal experiences through individual engagement lays the foundation for subsequent learning stages. Mainly, what is the role of active exercises during the reflection, conceptualization and experimentation learning stages of the Kolb cycle? Here, the question is not regarding the effectiveness of active
versus passive models in all learning, but in delineating the circumstances under which active learning is most appropriate.

In identifying the most effective use of active learning exercises, it is easy to conflate two concepts: active vs. passive, and personal experience vs. knowledge construction. The difficulty is that knowledge construction is an important component of all stages learner development, but active tactics have minimal effectiveness during reflection and conceptualization stages of learning--though it should be noted that passive tactics have the same characteristic. However, active environments provide a more solid foundation, than passive environments, for successfully navigating these later stages, if previous arguments are to be believed. So, in summary, active learning approaches work well for developing personal experience, but knowledge construction requires other tools, such as repetition, quiet reflection, or knowledge application in a real-world scenario. However, nowhere in these stages does passive lecture show itself as the best option.

**Judicious Use.** The SEI model uses active exercises as a primary tactic in introductory physics courses, but relatively sparingly in advanced physics courses. This brings up the question, “How much is enough?” Or, for the active zealot, “How much is too much?” For example, a Brazilian study of industrial engineers highlights a particularly relevant aspect of student preference. The study integrated a 3D model in engineering coursework, through either video or personal manipulation of the model. Findings indicated that increased frequency of interaction resulted in increased interest. However, comprehension actually declined at the highest frequency of interaction (Pedra et al., 2015). Another study showed that ‘medium’ frequency group work had an optimal
point for comprehension, above and below which, understanding suffered (Prince, 2004). In other words, comprehension actually went down with increased frequency past the optimal point, in both cases. Student mastery is distinct from student attitude, even if the concepts heavily relate. While improved attitude may often lead to increased performance, it is not an absolute relationship. Moreover, what may be best for student cognitive development may not necessarily lead to positive response. These findings highlight that multiple variables (performance vs. satisfaction, in this case) must be balanced in implementation of active exercises. This concept may be one reason why active learning environments can vary so substantially in different courses (S. V. Chasteen et al., 2011; S. V. Chasteen et al., 2015). The implications of this complex balance fall outside the scope of this research.

Not only must the frequency of active learning exercises be handled carefully, but so must the scope of the activities. The clear majority of physics education focuses on comparing traditional and specific progressive techniques: For example, the Perkins (2009) study contrasted traditional lectures with those implementing regular clicker and peer-discussion, without examining more active approaches to the class. However, the better question may be how to balance progressive techniques to achieve the optimal outcomes. In other words, what type of active exercises are best? For which characteristics (performance, memory, motivation, satisfaction, discipline, etc.)? While the reductive tendencies of science may overly simplify the human education experience, these types of questions can lead to more informed development of effective classroom models.
Finally, adding active learning exercises to upper-level courses can be practically difficult, as the types of concepts studied are not readily observed in everyday experiences (Electromagnetism [EM], Quantum Mechanics [QM], Statistical Mechanics, etc.). Some might suggest this last point increases the need for active learning, so that students can continue to build on personal experience. Upperclass physicists have also developed a cognitive structure whose currency is concepts, where personal experience might be less relevant for their growth; Or it might be that the good (clickers and conceptual thinking) is the enemy of the best (active exercises and personal experience of various EM or QM phenomena). The research is relatively silent on these questions, yet they must be fully explored if active learning is to be sustainably integrated in the STEM classroom.

**Summary.** In summary, active practices are necessary component of effective learning. A sampling of several of the most influential education philosophies and theories have shown that active learning is critical from a variety of perspectives: intrinsic motivation (Dweck’s Motivational Theory), progress through content knowledge (Kolb’s Experiential Learning Cycle), mental structure reorganization (Piaget), growth as an expert (Lave and Wenger’s Situated Learning), construction of knowledge (Dewey’s constructivism), and cognitive growth (cognitive psychology). Nowhere do any of these models suggest that the mere collection of information constitutes a critical component of education. While many research studies have shown positive effects of various active learning practices, this seems to be a misguided task. It is better viewed not as an
intervention, but as a core component of quality education, according to progressive approaches to knowledge.

**Physics Education Research**

Physics Education Research is a field that has been at the leading edge of reform in STEM innovations for several decades. In fact, a number of institutions have graduate degree programs that focus specifically on physics education. The contribution that the field has made to implementing progressive, and often more effective, teaching techniques is profound, especially at the post-secondary level.

Of relevance to this research, the extensive resources that have been devoted to creating models that expose students to physical phenomena reflect the very specific lens through which physics education field views education. The primary goal of education, according to the clear majority of physic education research, is to craft learners who demonstrate conceptual mastery and practice meta-cognitive skills that ensure accurate understanding of the natural world (Hake, 1998; Mazur, 1999). Concepts such as intrinsic motivation, satisfaction, and higher-order cognition (according to Bloom’s taxonomy) are rarely addressed, and only incidentally as they effect concept mastery or problem-solving skills (Carr & McKagan, 2009; Marshman & Singh, 2015; Singh & Marshman, 2015). This focus contrasts with more comprehensive approaches, usually taken in the social sciences (several of which have been discussed thus far); for example, the humanities might strive to understand an alternate worldview to appreciate a different perspective-- such as in Perry’s *Commitment to Relativism* (Moore, 1994)-- whereas physics education might do so to identify its fallacies (Mason & Singh, 2010).
Focus on Conceptual Understanding

The most striking characteristic of the physics education approach involves the ubiquitous presence of quantitative measurements, from test scores to student opinions via Likert Scale (S. V. Chasteen et al., 2015; Deslauriers et al., 2011; 2011) The exception that proves the rule is an article on quantum notations, *Transforming Upper-division Quantum Mechanics: Learning Goals and Assessment* -- the only carefully constructed qualitative study of quantum mechanics that was reviewed for this paper (Gire & Price, 2015). Researchers used a semi-structured interview approach to explore student perception and use of quantum notation. They were careful about not generalizing qualitative results, and they thought about being "representative of larger populations" (even if they used post-positivist vocabulary, such as *saturation*). And, both authors respected validity concerns by reviewing narratives of the interviews until they agreed on how to interpret them. Moreover, the interpretation was conducted through a theoretical lens of problem-solving. Finally, they provided various themes (and their features), and they had a number of student examples to illustrate central points. While this study also focused on problem-solving skills (like conceptual mastery and meta-cognition), it was the only one reviewed that explicitly acknowledged the researcher’s lens (Gire & Price, 2015).

A more common non-quantitative method than Gire & Price’s (2015) qualitative study is a mixed-methods approach that includes student response or limited interview, as follow-up to quantitative analysis. While most studies use student comments more for anecdotal purposes (Carr & McKagan, 2009; McKagan et al., 2008), Singh and Marshman’s (2015) exploration of student difficulties in quantum followed mixed-
methods good practices. They used semi-structured interview approach for a sample of participants (thought the selection criteria or technique was not clear), with quantitative methodologies use for the larger population. The interview task was verbalizing thought processes during problem solving— in other words, metacognition on problem-solving skills, with focused clarification questions. This was combined with quantitative analysis to identify 41 different difficult concepts, and how students often misunderstood them. While the interview technique is to be commended (for its exploration of a rich student experience), the limited focus is typical to physics education (Singh & Marshman, 2015). The scope of the research was on concept mastery and problem-solving skills, without reference to other aspects of the student experience. This is particularly troubling, as they were aware of the limited literature on student experience in quantum mechanics: “While the studies discussed so far have focused explicitly on investigating students’ difficulties with various topics in upper-level quantum mechanics, fewer studies have focused explicitly on students’ problem-solving and self-monitoring skills” (Singh & Marshman, 2015, p. 18). Moreover, Singh’s and Marshman’s study missed an opportunity to include softer aspects of the student experience, such as motivation or obstacles to learning, in their characterization of student growth. The two studies mentioned by Singh and Marshman are discussed later (Lin & Singh, 2009; Mason & Singh, 2010).

Even physics research that critiques traditional educational approaches often simply focuses on outcomes of mastery and problem-solving. For example, Hake’s (1998) meta-analysis on interactive engagement in the physics classroom conducted
thorough analysis of conceptual improvement during various types of physics classes, categorized by the level of engagement used during instruction. While the study showed demonstrably superior results for more interactive classrooms, it failed to explore other student characteristics, such as motivation or satisfaction. Another example is a book chapter, *The Increasing Importance of Learning How to Learn*, which covers issues in learning, such as interleaving, blocking, learning styles, but largely ignored many other measures of student growth (Astin, 1993; Bjork & Yan, 2014). Even when talking about metacognition, physics education researchers generally takes a content-driven approach to thinking: Any other characteristics of the learner which are not obviously related to concept mastery are ignored.

Related to mastery, physics education research often talks about meta-cognition and self-regulation. However, their terms are directed primarily to developing content-based reflection: the point of understanding multiple perspectives (in physics) is to find the one that is flawed (Mazur, 1999). While there are some aspects of metacognitive reflection vocabulary in PER literature (such as self-regulation), it is usually used solely to ensure accuracy of content knowledge. Within STEM education, *content-based* reflection is predominantly the focus. On the other hand, scholars in the humanities have identified four types of reflection: content-based, metacognitive, self-authorship, and transformative (Grossman, 2008; van Gelder, 2005). Content-based reflection is the most basic, but there are much deeper and more developed categories of reflection that support student growth.
Occasionally, physics researchers acknowledge and reference contributions of humanities-based education researchers in their studies: Singh and Marshman (2015) apply a cognitive apprenticeship framework to specific ideas in classical mechanics and quantum mechanics. However, Singh’s discussion, like many in PER, is mostly aimed at accomplishing content mastery, choosing to discuss specific tools that support this goal. For example, while Singh and Marshman make note of Vygotsky’s *Zone of Proximal Development* in an isolated, incidental reference, PER references to established education theories are rare. And Prince’s (2004) apparently broad assessment of learning goals (in comparison to most other PER studies) doesn’t even address items such as metacognitive awareness or student growth: “When asking whether active learning ‘works,’ the broad range of outcomes should be considered such as measures of factual knowledge, relevant skills and student attitudes, and pragmatic items as student retention in academic programs” (p. 2).

In a good example of STEM research that contrasts the physics education approach, Pang (2010) explored the effects of active learning on metacognitive traits. She referenced education theory and talked about the various aspects of the student experience. The research explored metacognition, higher-order thinking, and interpretation of alternative viewpoints, through the lens of an explicitly constructivist perspective (Pang, 2010). This provides a more comprehensive, nuanced, and realistic treatment of metacognition.

More work is needed to understand not only the cognitive response to active learning interventions, but also responses that include student success, persistence, and
satisfaction (Pascarella & Terenzini, 2005; Singh & Marshman, 2015). Students are complex beings, with a myriad of characteristics that influence their growth, such as motivation, critical thinking, affect, and self-efficacy. These forces interact in the classroom, and no amount of multi-variate analysis will ever be able to codify the human experience. This gap in research will become increasingly important as active learning practices are increasingly implemented.

The Advanced Environment

The Student

Upperclass students demonstrate higher levels of quantitative reasoning, which may reflect more detailed understanding of concepts (Hake, 1998), even if the precise scope and pathway for these improvements is not deeply understood (Singh & Marshman, 2015). A longitudinal study of active learning effects in electricity and magnetism found that freshmen showed significantly higher conceptual scores than their passively-taught counterparts. However, their exam scores—seen as a reflection of calculation-based skills—showed no significant difference. Upper-level students demonstrated similar trends, indicating that both introductory and upper-level students respond with some similarity to active exercises. And, Singh et al. found remarkable improvements in solving reasoning problems with active interventions in undergraduate EM and QM courses, but limited improvements in calculation-based problems (Singh et al., 2006). On the other hand, exploration of the most advanced physics students reflected a different relationship: Research of graduate physics students found that there was correlation between calculation-based and concept-based expertise in quantum
mechanics (Carr & McKagan, 2009). This may indicate that more advanced students respond differently to active environments, or it may indicate that calculation- and concept-based expertise is more closely aligned with more advanced content or more advanced students. More research is needed to explore the exact source of difference in quantitative-based skills.

An example about the confusion and complexity surrounding the source of content-related growth is Pollock’s (2009) longitudinal study of students in EM. While underclass students showed improved conceptual understanding due to active learning practices, the most noticeable differences occurred elsewhere. Advanced students who had taken transformed intro EM classes showed demonstrably more conceptual mastery improvement over the course of their later EM class. On the other hand, students who had not experienced active approaches in one (or both) of their EM classes showed marginal conceptual improvement. Pollock claims that the difference is due to the lasting effects of conceptual mastery gained during active practices: “Apparently some of the qualitative understanding built at the introductory level persists over time, and continues to benefit students at the upper-division level, as evidenced by improved [conceptual] scores and marginally improved grades” (Pollock, 2009, p. 7). But one may ask if the progress due to familiarity with the active environment, in a way that lightens cognitive load during instruction? Or, does student transfer between universities (a common trait for one subset ion of Pollock’s study) influence their performance, or preselect for certain characteristics?
It should be pointed out that the longitudinal nature of the study enabled the researchers to compare only physics majors, so the effect of self-selection to upper-level physics courses was accounted for: “Any conclusions we draw about long-term longitudinal impact of introductory reforms should therefore be interpreted as telling us directly only about the subpopulation of future physics majors, not the introductory level student population as a whole.” (Pollock, 2009, p. 3)

This brings up an interesting question: Is it possible many of the differences between introductory and advanced physics students is merely a reflection of the types of students in the classes? In other words, are characteristics, such as complex thinking, motivation, and conceptual mastery, observed in upperclass students, because those with lower skills have been weeded out? Or, how much improvement in meta-cognitive skills do future physics majors experience during their growth as students? Or, to complicate the discussion even more, researchers don’t fully understand the implications of active environments on the overall growth of the student as a scholar. For example, Chasteen and Perkins (2014) discussed the pervasive nature of course transformation of lower-level UC classes, using Peer Instruction (Mazur, 1999) and group activities (instead of labs, work on common misconceptions). Combined with Pollock’s longitudinal results, it seems there are lasting effects of these interventions throughout the college physics career (S. Chasteen & Perkins, 2014). This may color the entire experience of upper-level students in a transformed environment.

One of the ways in which advanced students clearly differ from their less experienced counterparts is that of familiarity with the lecture model, which may
complicate their transition to an active environment. As upperclass students, they have a long history of navigating a traditional model. As STEM students, they have shown themselves to be the most highly capable and successful students in navigating that model (S. V. Chasteen et al., 2012). Hence, it is to be expected that these students show more sensitivity to active exercises in the classroom than their underclass humanities counterparts (Hake, 1998). In fact, the data of this research reflect this sensitivity with a broad range of affective response, especially during the transition process.

Physics education research in active learning suggests several characteristics that distinguish the upper level physics environment from its introductory counterpart. Chasteen et al. (2012) outline a compelling argument for three unique aspects of the advanced environment:

1. Upper-level students are the “strongest, most committed, and best prepared students from lower-division courses…” Interventions often profit the weakest students, so a selected population consisting of the strongest students may give different results.

2. The material is fundamentally difficult, which may introduce unexpected complications in active exercise implementation. For example, due to complexity of the content, even the best of students require time to digest the material to reach deep levels of understanding (McKagan, Wieman, Heron, McCullough, & Marx, 2006).

3. The material is isolated, both in academia and in the real world. Students seldom come across QM outside of a QM class—not in other physics classes
and not in the real world around them. As a result, incidental retrieval is minimal, which mitigates external influences on content mastery (McKagan et al., 2006).

However, not all researchers are as emphatic about the uniqueness of upper-level students. Singh and Marshman (2015) found strong similarities between challenges facing introductory and advanced physics content. The authors suggest that expertise may be content-specific, explaining that skills developed during classical mechanics may not transfer to quantum mechanics. By interpreting various conceptual obstacles that face intro (classical mechanics) and upper-level physicists (quantum mechanics) through a cognitive apprenticeship framework, they were able to build evidence to support using this framework for physics education. For example, both content types involve a paradigm shift, they have diversity in student skill, and they are influenced by motivation and preparation (Marshman & Singh, 2015).

While specific parallels may justify using a framework for talking about teaching and learning at all STEM levels, this does not discount the previous arguments for their differences. Rather, it provides a way to understand both various students and varied content, while making a paradigm shift. For example, Singh and Marshman’s (2015) framework likens the correction of common misconceptions of Newtonian mechanics with the paradigm shift involved in understanding wave behavior. However, classical mechanics misconceptions may be conveniently addressed with classroom demonstrations. On the other hand, quantum mechanics studies behavior that is categorically unlike anything seen in the macroscopic world—the mystery of the dual slit
experiment, 3D quantum orbitals, and entanglement are a representative sampling of concepts that have no accurate parallel in the observable world. Finally, while arguments suggesting that meta-cognitive skills may not transfer across disparate disciplines (molecular biology and history, for example) might have some foundation, there are many characteristics of meta-cognition that span the learning experience (e.g. critical awareness of conceptual competence or intentionally using specific learning techniques), regardless of discipline.

One of the key components of a mature scholar is the ability to reflect on their cognitive process. Physics education research locates self-regulation, conceptual categorization, and epistemological awareness under the umbrella of metacognition (Hake, 1998; Marshman & Singh, 2015; Pollock, 2009; Singh & Marshman, 2015). Hake (1998) suggests that successful physics students have demonstrated successful metacognitive skills in working through the difficult curriculum of physics.

On the other hand, Marshman and Singh’s (2015) argument that some students have failed to develop meta-cognitive skills during their studies is supported by other research; In other words, experience does not necessarily develop expertise or complex thinking patterns. Furthermore, Carr and McKagan’s (2009) study of graduate quantum mechanics students found that graduate students often demonstrated similar conceptual understanding as their undergraduate counterparts. In addition, they often did not meet instructor expectation of conceptual knowledge, and additional instruction often did not correct underlying misconceptions. And, in another journal article, Singh and Marshman (2015) explored a number of common misconceptions in upper-level quantum
mechanics, finding that upper-level students often do not demonstrate the types of meta-
cognitive skills (such as organizational structure) normally expected of advanced students
(2015). Finally, Lin and Singh (2009) compared faculty and student categorization of
quantum problems to clarify student ability to think like a physics expert. They found
that students thought of quantum mechanics challenges in a less comprehensive way than
professors. While the authors argued that the results were an indication of poorly
developed meta-cognitive skills, their findings may be explained by the limited
perspective of even advanced students while they are still learning a field. Moreover,
while the analysis involved interview, the task was challenging and complex enough that
even the evaluators found that some of the participants provided perspectives that were
better than their own (Lin & Singh, 2009). Another possible explanation may lie in the
inherent difficulty and abstract nature of quantum mechanics (McKagan et al., 2008).
Combined with a percolation model of knowledge construction, which describes the
long-term development of expert-like knowledge architecture, it may be completely
unreasonable to expect undergraduate physics students (regardless of class standing) to
develop a coherent structure for such a complex and difficulty field of knowledge.

The lack of a clear understanding of upper level student metacognitive skills is
not surprising: little is known about middle to high metacognitive skills, compared to
underclass students (Schraw, 1998). Part of the problem may lie in confusing surface-
level content mastery with deeper metacognitive skills. For example, “One common
assumption of many physics instructors is that a majority of upper-level physics students
are like them,” having developed significantly better problem-solving, reasoning, and
metacognitive skills than students in introductory physics” (Singh & Marshman, 2015, p. 2). Instructors may also presume that, even without guidance and scaffolding support, upper-level students will automatically focus on building a robust knowledge structure of physics. In particular, many instructors assume that most upper-level physics students have developed good learning strategies, are eager and primed to learn in all their courses, and are unlikely to struggle in the same manner as students in introductory courses. (Marshman & Singh, 2015). Finally, upper level students show a particularly broad spectrum of meta-cognitive skills and content mastery, additionally confounding attempts to understand how their level of cognition develops (Marshman & Singh, 2015).

In summary, evidence distinguishing characteristics of upper-level physicists from their more novice counterparts are compelling, even in the face of criticism—and one would hope as much, given the time and energy devoted to schooling during the first 3 years of college. However, it should be remembered that advancement through the curriculum is more an indicator of growth as a scholar than a guarantee of it. Moreover, it may be that the most persistent immature behaviors are a function of the typical passive learning environment. On the other hand, it would be incorrect to presume that traditional techniques have not validity simply because they are not progressive: After all, traditional techniques have stood the test of time because of their utility and effectiveness. For example, after an extensive review of various student difficulties in upper-level quantum mechanics, Singh and Marshman (2015) conclude,

…it is inappropriate to assume that, because they have made it through the introductory and intermediate physics courses, all students in upper-level quantum mechanics will develop sufficient expertise in quantum mechanics after traditional instruction. In fact, the diversity in student performance in
categorization of quantum mechanics problems suggests that many students are getting distracted by the “surface features” of the problem and have difficulty recognizing the deep features which are related to how to solve the problem. The fact that many students are struggling to build a robust knowledge structure in a traditionally taught quantum mechanics course suggests that it is inappropriate to assume that teaching by telling is effective for most of these students because it worked for the professors when they were students (p. 19).

In fact, the Chasteen (2012) (and others) cite poor performance of advanced students— at all levels— in their call for improved approaches for advanced EM and QM courses (Singh et al., 2006). It may very well be that all students, regardless of learning stage, are deeply affected by the quality of their learning experience.

The Curriculum

Advanced courses differ from introductory courses regarding the complexity of the knowledge that must be used to understand difficult concepts. While classical mechanics may be understood with basic trigonometry and algebra, the mathematical concepts required for quantum include linear algebra, calculus, and statistics, as well as a firm grasp on electricity, magnetism and waves (Singh, 2005). Once again, after a careful look at the types of challenges faced in quantum mechanics, investigators conclude: “Learning upper-level physics is also challenging because one must continue to build on all of the prior knowledge acquired at the introductory and intermediate levels. In addition, the mathematical sophistication required is generally significantly higher for upper-level physics” (Singh & Marshman, 2015, p. 1).

Per Chasteen (2012), and others, upper level material is fundamentally difficult, isolated from physical observation, and not encountered in other courses (McKagan et al., 2006). While other researchers categorize the unique aspects of quantum mechanics
differently, the basic themes agree (McKagan et al., 2008). To add to the isolation, relatively little research has been conducted on active learning in these areas. Recently, more work has been done to explore and measure the effects of active learning in upper-level physics courses. For example, the American Physical Society has an entire *Upper-Division Physics Courses Focused Collection* ("Upper-Division Physics Courses Focused Collection," 2017). However, the quantity of research on active learning is still rather limited. What little research that does exist often focuses quantitatively on concept-based cognitive outcomes, such as Dirac notation (Gire & Price, 2015; Goldhaber et al., 2009; McKagan et al., 2006; Singh & Marshman, 2015).

**Quantum Mechanics**

Some research has explored student perceptions of active learning in quantum mechanics, but inquiry beyond easily measured variables, such as conceptual mastery, is weak, at best. This shouldn’t be surprising, given the inclination of the physics education field to focus on content knowledge combined with the prevalence of research in introductory courses. Perkins et al. (2009) found that upperclass physics students identified several major perceived advantages of active learning exercises: improved mastery, dedicated focus on topic, and increased active processing. However, this study really only explored the integration of clickers within a peer-instruction model (Mazur, 1999), so use of concept exploration, simulations, and formative quizzes were not explored. And, the qualitative data collection only consisted of short answer response, missing an opportunity to explore other student factors, such as motivation, previous experiences, or insights gained. Chasteen et al. (2012) used a mixed-methods approach
to explore active learning in Electricity and Magnetism (EM). In fact, the authors (and others) cite poor performance of advanced students- at all levels- in their call for improved approaches for advanced EM and QM courses (Singh et al., 2006). It should be noted that the EM study found remarkable improvements in solving reasoning problems, but limited improvements in calculation-based problems. In addition, they saw improved satisfaction with the class overall. Finally, they found students valued challenging conceptual questions in class and optional help / tutorial session outside of class (S. V. Chasteen et al., 2012). While their qualitative survey identified positive effects from active learning, they neglected to explore reasons for these responses, or any additional comments on the student experience. Finally, Mason and Singh (2010) explored students’ ability to learn from their mistakes, using a mixed methods design. Fourteen advanced physics students were given the same problems on the mid-term and the final exams, to identify if they were able to learn from their mistakes. They found that there was a wide distribution of performance on the final exam, with half the students learning from their mistakes and half not learning; This reflects earlier comments about the diversity in graduate student competence (Carr & McKagan, 2009). After the final exam, four students were interviewed about their problem-solving approach. Once again, the interview neglected to explore non-conceptual based topics, choosing rather to focus on the types of conceptual and calculation-based mastery the participants were able to explain. Moreover, with only four paid subjects, sampling bias may be an issue. And, while they did ask about attitudes towards problem-solving and learning, which could- in
theory- touch on topics such as motivation and personal history, it is clear from the journal article that the focus of the analysis was on content mastery.

These types of questions hint at the relatively limited scope of our understanding of advanced students, and the developmental growth that may characterize them:

… little is actually known about how expertise in physics develops as a student makes a transition from introductory to intermediate to advanced physics courses and whether the cognitive and metacognitive skills of advanced students are significantly superior to those of physics majors in the introductory and intermediate level courses (Singh & Marshman, 2015, p. 1).

For example, some ask if growth happens continuously or in steps:

Little is actually known about whether the development of these skills from the introductory level until the students become physics professors is a continuous process of development or whether there are some discontinuous “boots” in this process, for example, when they become involved in graduate research or when they independently start teaching and researching. There is also no research data on the fraction of students who have gone through the traditional physics curriculum and have been unable to develop sufficient learning and self-monitoring skills (Mason & Singh, 2010, p. 760).

Qualitative research of upper-level STEM students would provide insight into these questions regarding advanced students.

Summary

Combined, findings from the research presented in this literature review suggest that effective teaching practices effect student growth (Freeman et al., 2014). While PER is focusing on certain aspects of the student experience, those aspects account for a limited scope of student education. Moreover, the uniqueness of the advanced environment has been acknowledged, but not thoroughly explored. As a result, little is
known about non-cognitive aspects of student engagement in an advanced physics environment. This study explored the students’ engagement during a course transformation to active learning, in an effort to close this gap in the literature.
METHODS

Introduction

I used a case study approach to explore participant response to active learning interventions in an upper-level quantum mechanics course. A postpositivist framework was used to capture and order prominent themes of participant cognitive, affective and behavioral engagement, while still providing structure for exploration of complex experiences. Qualitative methods were used to explore participant experience through interviews, observation, journaling, and a focus group. I began the qualitative analysis iterative process based on a framework supported by the literature review, Chapter 2. The literature review provided insight into common themes and influences in the advanced physics active learning environment, such as satisfaction, improved conceptual mastery, varied responses, and operationalization challenges. Finally, I used Fredrick’s (2004) engagement framework to interpret overall student response, with the intent of exploring how students respond to active learning interventions, and which interventions are most impactful.

Research Design

I used qualitative methods, in the context of a case study methodology, to explore student response to active interventions. Case study boundaries included one semester of an upper-level quantum physics college course, including class time and optional out-of-
class gatherings. Both students and instructor were subjects of research. The use of qualitative methods requires clear positionality and sensitive response to emergent themes. Constant bracketing was necessary to distinguish my roles as Graduate Teaching Assistant (GTA) and Researcher. Finally, I used rigorous analysis of all data in an iterative fashion to identify emergent themes (Bazeley, 2009; Creswell, 2013b; L.R. Gay, 2009b; Maxwell, 2013).

**Reflexivity Statement**

A reflexivity statement provides insight into the factors that influence my relationship with the study, its participants, and the analysis. My unique background as a non-traditional student and researcher, as well as my central role in this study, justify a thorough reflexivity statement. Most notably, I developed the active learning activities used in this study, based mostly on my experiences during the education Masters program. Likewise, I designed and implemented the research design methodology based on my Masters studies.

A number of personal experiences and interests directly related to this study. I have created 100s of Khan-style videos (KSV), in engineering, which drove my interest in creating pre-lecture videos for this project. My recent successful completion of the class provided a fresh perspective on learning quantum mechanics, which informed lesson plan development; However, execution of daily lessons was fully in the instructor’s purview. As a researcher, I treated my regular presence in the classroom delicately, trying to minimize my impact by sitting in the back row, as discreetly as possible.
As a masters student in education, with constructivist leanings, I’ve become interested in how students develop their whole being, not just conceptual mastery. Hence, a qualitative study provided a technique for exploring complexities of the student experience. Finally, as an engineer, my undergraduate experience is similar, yet distinct, to those of the physics majors in the study. This evoked an outsider’s curiosity, with an insider’s understanding. The cultural distance between myself and the participants prompted my practice of following up participant interview responses with thematic clarification questions, such as “I hear you saying that…” The cultural proximity cultivated a warmth and relational connection outside of class with most of the students: Many became friends.

For this study, I have developed the research design, collected and analyzed data, and developed the transformation curriculum in partnership with the instructor. This leaves me with deep personal interest in the success of the project. It was important to me to be both open about my investment and thoughtful about my approach to maintain the integrity of this study. However, it is important to clarify what this personal interest means to me.

A note of my personal stance on active learning before embarking on this study is also in order. While the loud voice in STEM is to implement active learning everywhere, I find the chorus to be more cacophony than harmony. I find it hard to believe such a simplistic view of an educational problem can provide lasting progress. How much active learning? When? What does the actual evidence report? I believe that sincere and authentic inquiry, in a safe environment, thoughtfully constructed, can provide glimpses
into complex questions. I have done my best to listen to the study, and report what evidence and insights I’ve found.

**Setting**

The context for this study was Quantum Mechanics 1, an upper-level quantum mechanics course, at a large Rocky Mountain land-grant university. This case was chosen because of the instructor’s highly motivated approach to instructional innovation. Moreover, convenience influenced the decision, because of access opportunities to the class, and because of a strong working relationship with the instructor. The content spanned a full semester of class during the Fall of 2017. Class met three times per week for 50-minutes, with flexible GTA and instructor office hours. The class is three credits and is a required class for all physics majors.

Curriculum for Quantum Mechanics 1 covers 1-D potential wave characteristics, formalism (Dirac notation, etc.), 3-D potential wave characteristics, and an introduction to spinors and angular momentum, following chapters 1-4 of Griffiths’s (2016) seminal quantum textbook.

**Intervention**

The developed class activities followed the basic structure of the upper-level SEI model: lecture-based content presentations, alternating with small-group active learning tasks, rotating in 5-10 minute time chunks (Deslauriers et al., 2011). Active exercises were used an average of 25 minutes of the class time, varying from 0 minutes at the least to 39 minutes at the most. Learning tasks were varied, to provide a broad range of interactions, such as *muddiest point* exercises, simulations, problem-based board work,
derivations, and minute papers (Cross & Angelo, 1988; Gray & Madson, 2007; Grossman, 2008). Appendix H includes a sampling of lesson plans integrating various interactive activities. This model incorporated a limited lecture model, with 1-3 group-based activities during each class. For advanced material, while building knowledge on personal experience (such as a simulation or exercise) is essential, the amount of time and expertise to make sense of the experience is extensive; Lecture is essential (S. Chasteen & Perkins, 2014). Structured homework assignments were used three times during the semester, based heavily on CU’s (University of Colorado) SEI (Science Education Initiative) resources; Structured homework assignments consisted of 1-2 problems, with multiple parts. The parts provided a scaffolding for directing thought through a complex problem. They were largely concept-based, and focused on common quantum mechanics misconceptions.

In addition, progressive approaches not typically used in the SEI model were integrated into the class: formative quizzes, structured homework assignments, Just-in-time-teaching techniques, problem-solving sessions, and pre-lecture videos. Formative quizzes were used, often at the beginning of class, to test conceptual mastery, followed by a summary or discussion of the concept.

Traditional homework assignments consisted of 2-4 challenging problems that used knowledge from class (and assigned reading). They were often technically and conceptually rigorous, taking 1-4 hours to complete. All homework assignments were graded in advance of the following class, so common themes / misconceptions / mistakes could be addressed in the opening 5-10 minutes of class. In other words, homework
assigned during Monday’s class was submitted by noon Wednesday, and graded, with feedback, by Wednesday’s 2pm class. While a constrained timeline, the amount of time for review of homework was identical to traditional approaches. Most importantly, the instructor could address student misconceptions at the beginning of class, as well as answer any questions that emerged in the homework before continuing to the next topic. Homework completion rate was 91%, and the quality of work was graded at 87% (class average).

As content increased in difficulty, an optional Thursday problem-solving session was created, in addition to office hours. Students brought their own questions, commonly on homework due the next day (Friday). There were usually 3-5 students in attendance—often the same students—unless there was a particularly lengthy homework assignment or an upcoming test.

In addition, pre-lecture Khan-style videos (KSV) prepared students for class activities. Thirty-three videos were used, 3-11 minutes long, with an average length of 5:26. Videos followed CLT’s nine principles in a standardized format (R. Mayer, 2009; Richard E. Mayer, 2005). Conformance to video use expectation was tracked by course management software; students showed moderate to strong adherence to viewing expectations.

In summary, the intervention implemented a multi-prong approach to student learning needs. An open-dialogue style during lecture increased student interaction and clarification during lecture. Weekly problem-solving sessions provided a more intimate coaching and weaning structure for developing problem-solving skills. Formative
quizzes provided an objective assessment of student mastery. Pre-lecture videos presented conceptual material outside of class, so any clarification points could be addressed in the beginning of class. Misconceptions uncovered during review of submitted homework could be addressed at the beginning of class, as well. Concept review and formative quizzes provided an effective transition into class. Finally, all activities aligned with learning targets.

**Emergent Design**

Qualitative inquiry is based on the emergence of themes during the research process. During this study, the research design itself changed in two notable ways, as a result of a feedback loop with participants informing actual intervention practices. First, the initial class structure closely followed the SEI model for introductory classes (Deslauriers et al., 2011). Class periods revolved around 3-4 active exercises, with instructor feedback and group discussion to explore and adjust student understanding— instructor lecture was minimal. In addition, homework assignments were due 24 hours after class (unless additional help was requested): This Just-in-Time-Teaching (JITT) strategy gave students time to complete assignments and prepare for class in a structured way, and it gave the instructor time to modify class to address student misconceptions. This format was used (instead of the SEI model for advanced classes) because it was the more ‘extreme’ of the two models, and it was envisioned that lessening the influence of the intervention would be a more amenable adjustment (to the participants) than increasing it—in the event a correction was required.
In fact, a correction was required. Student feedback during this time (the first two weeks of class) was very critical of the structure. Students found it to be too hurried, as activities often took longer than expected. Students reported that there was inadequate time for discussion of new material, leaving them ill-prepared for homework assignments. They did not feel that they were exploring the material sufficiently in-depth, as minimal lecture explored deeper concepts. And, they did not find the exercises to be sufficiently valuable, as they often only looked at surface features of the phenomenon and discussion about them lacked depth. In responses to this feedback, the instructor and I adjusted the class approach, to more closely follow the SEI transformation model for advanced classes (such as QM 1), at the beginning of week three. This class structure has been discussed in detail previously. Student response immediately changed to more positive feedback, highlighting the value of feedback and course correction during implementation of active learning (Huba & Freed, 2001; Petersen & Gorman, 2014; Shimazoe & Aldrich, 2010). In fact, this adjustment was explicitly mentioned by almost every participant during the second round of interviews:

While the adjustment had been made in-time for the first round of interviews (week 4), there seemed to be inadequate time for participants to clearly reflect on the modified format.

Second, several complications arose due to suboptimal operationalization of active learning interventions, due to an inappropriate model for physics transformations. Because both the literature and the pilot study revealed that effective operationalization of active exercises was highly important for student positive participation, extensive work
focused on developing coherent lesson plans with effective exercises (Warren, 1997). However, the relative inexperience of both the instructor and the researcher resulted in several active exercises that seemed to lack focus, to not address critical skills, or to unnecessarily disrupt the class flow, according to both student feedback and classroom observation reports. In addition, large time investment, especially on the part of the instructor during class preparation, differed from some literature claims (S. V. Chasteen et al., 2012; S. V. Chasteen et al., 2015). These factors, combined with an inappropriate SEI model, may have disproportionally influenced student response to active learning during the first four weeks (or so). However, these types of roadblocks are not uncommon for faculty trying to implement progressive practices (Petersen & Gorman, 2014) (Roehling et al., 2010). Hence, the type of responses encountered during this study may be somewhat typical for faculty attempting this type of transformation in advanced physics courses.

Participants

The participants were mostly senior physics majors and their instructor. 13 students were enrolled in the class: 11 of these students are physics majors, the two remaining students were graduate students in material science. From these, one physics major and one graduate student dropped the class, but data were still collected, when participant feedback was relevant. All undergraduate participants have attended the university for most of their studies, with experiences in predominantly traditional education environments. What little experiences participants had in non-traditional environments were either isolated class interactive exercises or cookbook labs. This
cohort of students had particularly strong relationships, possibly due to having spent four years taking the same classes together, evidenced by their familiar tone during class and their collegial tone while working together outside of class. The majority of the physics majors continued with the subsequent quantum mechanics course.

Eleven of the thirteen participants (85%) participated in two personal interviews and in a class-wide focus group. Accounting for students who dropped the class, and the resulting loss in opportunity for data collection, the total participation was 92% (actual / possible in-person sessions = 36/39). The researcher informed the class of the study purpose and procedures in advance of the study. Students all demonstrated sincere interest in both success as scholars and interest in the purpose of the study. All participants signed and returned consent forms outside of class, per the IRB application (IRB number BT082417EX).

The instructor was a seasoned, tenured physics professor, with research expertise in fields overlapping with quantum mechanics. He had taught the course for the first time in the previous semester, following a traditional structure. His experience with progressive practices was limited, but he was highly motivated to explore alternative teaching techniques. The instructor could be described as a Masterful Facilitator, according to Lowman’s (1984) Two-Dimensional Model of Effective College Teaching, with a long record of research and instructional success within a traditional lecture model. With the implementation of a new teaching style, there was a steep learning curve that the instructor and researcher addressed enthusiastically and diligently. His personal teaching style reflected Grasha’s (1994) Facilitator, characterized by “the personal nature of
teacher-student interaction...[and an] overall goal... to develop in students the capacity for independent action and responsibility” (p. 143).

Data Collection

Data collection was performed according to qualitative good practices. A pilot study was implemented to provide insight into instrumentation and thematic elements of participant response. The primary instrument for data collection was one-on-one interviews. In addition, classroom observations were conducted, as well as problem-solving observations. And, student written response to active exercises were collected. Finally, a focus group provided opportunity for communal exploration of preliminary analysis themes. Each data collection point was included to support exploration of the research questions: A Table of Specifications (Appendix I) provides details regarding the data instruments and their purpose.

The timeline for varied data collection spans from March 2017 to December 2017. The pilot study was conducted March 2017. June-August 2017 involved development of instruments and pilot study analysis and results. The course under study in this research began late August 2017, with observation and student written responses conducted. The first round of interviews was conducted late September. Continued observations were conducted September through December. The second round of interviews was conducted early December. By mid-December, preliminary analysis had identified themes. In late December 2017, the focus group was conducted, immediately after the final exam for the semester. Final data analysis was conducted January of 2018. Appendix J illustrates the timeline of data collection and analysis.
Throughout the collection process, my role as a researcher were repeatedly and explicitly clarified to participants during interactions with them. In addition, participants were regularly encouraged, formally (through muddiest point or other class feedback mechanisms) and informally (through one-on-one discussion with the researcher or the instructor), to include honest feedback regarding the active interventions. Finally, bracketing was used constantly to distinguish my role as researcher from my role as GTA. In practice, this meant limiting my role as a GTA: I did not calculate overall homework averages or participate in exam grading, unless required for class management.

**Pilot Study**

A short-term pilot study was conducted in the Spring of 2017. It provided insight into significant aspects of the student transition to active learning environment, into the steps required to transform a class, into interview structure, and into variables in study design. A phenomenological study explored student response to active learning exercises and the most influential active learning exercises in Quantum Mechanics 2. The research questions for the pilot module paralleled the research questions for this study. The study spanned four 50-minute class sessions, while studying the WKB (Wentzel–Kramers–Brillouin) approximation. The WKB approximation is a topic that is covered in the second semester of advanced quantum mechanics: It would typically follow the content covered in this research study. The WKB approximation provides an approach for estimating energy levels and wave functions in certain potential well profiles. Six senior physics majors participated. One-on-one interviews and a focus group were conducted
with all participants. Similar data analysis strategies were used to this study, though I was a fellow student, rather than a GTA, which introduced other validity challenges.

The pilot study provided several insights that supported this study. First, it gave the researcher and instructor a chance to try out several teaching good-practices. Second, it provided a much more in-depth understanding of the types of experiences and perspectives that the students brought to the class, which was useful during follow-up questions in the interview stages. Third, it reaffirmed the engagement model, as summarized by *School Engagement: Potential of the Concept, State of the Evidence* (Fredricks et al., 2004), as a valid and applicable framework to view this study. Finally, it provided a starting point for the type of active exercises that would be best received within this particular institutional culture.

**Interviews and Focus Group**

Two rounds of one-on-one interviews were conducted with each participant, each interview lasting between 30 minutes to one hour. The first half of the interview explored overall participant description of the intervention, the most influential exercises that formed that perception, and any negative responses to the intervention. The second half of the interview explored response to the active exercises, from an engagement perspective. Participants were asked about their cognitive, behavioral, and affective responses to the intervention. They were then given the opportunity to talk about any aspect they wanted, through an open question: “Is there anything else you want to tell me?” Throughout the interview, follow-up questions were used to explore participant
experience more fully, according to semi-structured interview best practices (Maxwell, 2013).

Interview structure was slightly different between the first- and second-round interviews, to address research questions. The first-round interviews focused on student response during a transition from a predominantly traditional environment to a more active one. The first-round interviews recorded demographic information in addition to the above-mentioned questions (week 5). This oriented participants within the college community. The second-round interviews focused on how student response developed during a full-semester intervention. The second-round interviews explored differences between present participant responses and those given in the first-round interview, in addition to the above-mentioned questions (weeks 14-15). This provided a data point for comparing initial response to long-term response to an active environment. All interviews and the focus group started with a summary of the focus of the study and participant rights. Finally, the instruments were reviewed by a faculty committee, and approved by IRB before collecting data.

Interview questions followed Maxwell’s (2013) guidance for episodic interviews. The first question on a particular concept was asked in present tense, according to best practice. This tends to elicit generalizations and participant understanding of their experience. This type of question was asked first, as it tends to be less threatening. If the participant did not include specific examples, a follow-up question was asked, using past tense, according to episodic interview best practices. This approach tends to trigger *episodic memory*, which provides insight into the actual experience and improves
participant recollection clarity and accuracy (Maxwell, 2013). In this way, interviews explored both participant experience interpretation and details.

Once both one-on-one interviews (for all participants) were conducted and preliminary data analysis was complete, the researcher conducted a focus group that included 11/13 participants. The focus group explored preliminary themes that developed during analysis of the first two rounds of interviews, as well as noteworthy unique participant experiences. The focus group explored common responses within a cognitive, behavioral, and affective engagement framework.

Finally, the instructor was interviewed, using a semi-structured interview that was similar in format to that of the participants, at the completion of the semester. The interview questions focused on the instructor’s experience with the students and the content, as the leader of an active learning environment. Topics were explored within a cognitive, behavioral, and affective engagement framework. Appendices K-M detail interview and focus group structured questions.

Throughout the study, participants were encouraged to discuss ideas with one another, and were explicitly reminded that diverging opinions were of particular interest. At each interview, the students were reminded of the value of their perspective, and that the goal was to learn about their response, rather than make a case for or against active learning. All interviews and the focus group started with a summary of the focus of the study, definitions of terms, and participant rights (Appendix N). The attitude in all meetings was very informal, possibly due to my previous interactions and relationships with most of the participants.
Interviews and the focus group were recorded with a digital recorder and backup recording device, in their entirety. I conducted all interviews and transcribed them for analysis. To encourage participation in the focus group, pizza was served. I used memoing during the interviews and focus groups to note interesting content, for reference during analysis. Participants reviewed transcripts for accuracy.

**Triangulation and Complementarity**

In addition to the primary data collection instruments, several other data collection instruments were used: In-class feedback exercises, in-class observations, video viewer log, and problem-solving session observations. Additional data sources enabled triangulation and complementarity during data analysis. Triangulation refers to the phenomenon of identifying themes using data from several independent sources. For example, interview data may suggest that a particular active exercise was stressful, and in-class observations may indicate that students were agitated and frustrated during this exercise. The agreement of these data points strengthens the substance of related themes (Creswell, 2013a). Complementarity refers to the phenomenon of identifying different aspects of a particular theme using data from several independent sources (Maxwell, 2013). Using the above example, classroom observation may have also noted that only half of the class was agitated or frustrated, and the other half was energized, implying that stress during active exercises may be a concern for only some students. In this case, the in-class observation has added a nuance to the theme of stress that interview data alone may not have identified. In summary, loosely speaking, triangulation combines
data sources to find agreement, while complementarity combines data sources to find complexity, yet both ideas enhance qualitative exploration.

In-class feedback exercises were used regularly, usually weekly, to understand students. Both muddiest point and 1-minute paper techniques were used (Cross & Angelo, 1988). Exercises were conducted either at the beginning or end of class, and responses were anonymous. Responses related to engagement responses were used as data points. For muddiest point exercises, students were usually given the opportunity of asking about a conceptual difficulty or commenting on the active environment, and some students did both.

In-class observations were used for a two-fold purpose. Observations measured overall class engagement characteristics, following a two-page engagement rubric that reported significant events during lecture, from an engagement perspective, and their time (See Appendix O for an example raw rubric). In addition, observations measured individual students’ engagement activities, following the attached observation rubric (See Appendix P for an example raw rubric). Two students were observed during each class session, and each student was observed roughly two times. The observer sat towards the back of the class, with changing position to facilitate observation, where needed. Given the class size and activity level, recording this breadth of data during class sessions required focus and full engagement on the part of the observer. The observer attended 95% (36 / 38) of the study classes.

Video viewership was also used to gauge student interest in prelecture videos and overall class preparation. Video links were tracked using existing course management
software, so video viewership could be tracked, however duration of view data was not tracked. Because videos were located online (on the researcher’s YouTube account), this tracking technique was not robust, as some students preferred to simply subscribe to the respective YouTube playlist. However, discussion during interviews revealed that students were very open about their viewing habits, for both regular and intermittent viewers. It should be noted that students were notified that in-class quizzes (formative or summative) would assume they had watched relevant prelecture videos before class.

Scheduled and custom problem-solving session observations were also conducted. These observations gauged the types of questions and willingness to engage in a more informal setting. It should be noted that observations of these sessions occurred intermittently, roughly 50% (6 / 12) of the meetings. Similar rubric to the classroom overall engagement rubric were used to evaluate engagement during the problem-solving sessions.

Data Storage

Data was kept on the researcher’s local password-protected computer, an encrypted hard disk backup, and a password-protected online backup during collection and analysis. Once analysis was complete, all data was moved to the encrypted online backup, and removed from the local computer. The data will be kept until December 2020, after which time it will be deleted. This approach protects participant confidentiality and anonymity, as well as providing access should later access be required.
Data Analysis

All data was reviewed for significant statements that reflect the participant experience of an active environment or provide insight into characteristics of the case setting (Creswell, 2013a). These data points were categorized in an iterative process, until sensible categories could be identified—a technique called horizontalization. These categories were reformed and combined into a smaller number of coherent themes, and used to create cohesive understanding of an active environment, within the boundaries of the case (Maxwell, 2013).

Statements from transcriptions of all interviews were coded into categories, using NVivo. Initial categories were established using results from the pilot study phenomenological analysis. Iterative review of data restructured the categories until all data was included. Themes were identified through constant comparison of categories, within an engagement framework. In other words, each theme could be described by its behavioral, cognitive, and affective characteristics. Once identified, themes were interpreted within a conceptual framework informed by the literature review. These emergent themes were then couched within theories suggested by the literature review, so that a more complex understanding of the case study emerged. At this point, naturalistic generalizations were made about the findings, to inform future work in the field (Creswell, 2013a).

Throughout the analysis, I focused on maintaining tension, rather than forcing resolution, during the emergence of themes. In this way, themes could develop more naturally, rather than being interpreted solely through the lens of existing literature.
Moreover, additional latitude was given to divergent data, as these types of data may indicate weaknesses in existing explanations of active learning. For example, one student found many aspects of the active environment disengaging and frustrating; Inclusion of his experience provides a richer understanding of the student experience.

**Ethical Considerations**

The most significant ethical complication was my role as both GTA and researcher. This introduced a power structure into my role as a researcher. I addressed the power structure by limiting the scope of my GTA responsibilities, and by clarifying my role wherever there might be ambiguity, demonstrating good bracketing practices. For example, I didn’t view test scores, except where needed, during my GTA responsibilities. Also, as a grader for the homework assignments, I used a standardized rubric, and I submitted grades to the instructor without summary or full averages calculated for each student. During the interview process, I read a standardized introduction that clarified my role as a researcher, including participant anonymity during the interview process. These types of practices provided some insulation from data that was not to be used for this research, but more importantly, it functioned as a perpetual reminder of the need for bracketing.

A secondary ethical complication was my close relationship with the professor. This concern is mitigated by the informal and supportive class culture, as well as the professor’s sincere interest in supporting student success. In fact, students often noted his warm engagement as a major influence on positive engagement during the class. No thematic elements (from either interviews or focus group) were shared with the instructor
until after final grades were submitted. Even then, all care was taken to ensure the confidentiality of participant responses. In addition, it should be noted that I worked closely with the instructor to develop active material for the transformation, and the instructor also served as a member of my Masters committee. IRB approval ensured appropriate measures had been taken to minimize student risk exposure, to protect data storage (including retention timeframe), and to identify potential ethical concerns.

Validity Concerns

Researcher Role

Study design included neither class grades nor interactions outside of the interviews and focus groups, as valid data. While this data would have provided a richer description of the class, including class grades in data collection could introduce an unconscious bias as an interviewer, and it may complicate student self-reporting of their experience. Collecting data from interactions outside of the interviews and focus groups could easily conflate participant perception of my role as GTA and researcher. For example, if I was in a research role, complete anonymity could be guaranteed, but as a GTA my priority was to assess and feedback student performance to the instructor. By simplifying the bounds of the researcher role (interviews and in-class observation), clarity and transparency with participants was easier to maintain.

Due to the complex nature of qualitative research, accurate communication of participant experience is a credibility concern. Participant experience may be misheard; this was addressed through voice recording of interviews. Participant experience may be misunderstood; this was addressed by using a triangulation effect that included
respondent validation (of both interview transcripts and thick description of data), extended time in the field (as a GTA for the duration of the course and as an observer of 33/36 class sessions), and focus group discussion (Maxwell, 2013). Moreover, I often followed-up participant comments during interviews with a re-framing of the idea, starting with “I hear you saying that…” Researcher bias may unduly influence data analysis; this was addressed through reflexivity during positionality and external audit of data analysis techniques. Discrepant views that do not align with theory may be delegitimized; this was addressed by highlighting discrepant data, to gain insight into complexities of participant experience.

Transferability

Due to the peculiar setting of this study, transferability to other settings might be difficult. Transferability to other universities are addressed by explicit discussion of the study environment and participant background; researchers can identify variables that may influence how results overlap. Long-term study duration and multiple sources provided multiple faceted exposure to participant experience. Due to the student inexperience with quantum mechanics and the instructor’s lecture style, it is likely that some student response to active learning may have actually been caused by these unique course characteristics. While follow-up questions distinguished these sources during the interview stage, it was often difficult for participants to distinguish between the sources of their responses.

Due to the subjective nature of qualitative research, researcher bias raises confirmability concerns, especially given the close relationships between the participants
and the researcher. The lens through which the researcher interprets the data will color the results; this was clarified through reflexivity and explicit positionality statement, as detailed earlier. The researcher may unduly color the interview environment; this was addressed by using a standardized interview format that was subject to peer review during study design. In addition, while a standardized approach was used during the analysis procedure, comparing the analysis results between two researchers might have given a quantitative assessment of confirmability validity. On the other hand, because the inherent subjectivity of qualitative inquiry is a fundamental asset in developing richer descriptions, it may be that researcher authenticity may be a far more important concept than specific validity concerns.

One danger that exists for qualitative research is to allow preconceived notions to unduly color analysis, either through pilot study findings or literature review (Bazeley, 2009). In this case, analysis may simply apply themes seen during the literature review to the research data, thereby eliminating the possibility for new, or even authentic, themes to develop. While the literature review prepared the researcher for concepts that have been shown to surface during similar studies, the gap in the literature is sizable. One can easily make the case that advanced students have different experiences with active learning than others. And STEM students have been shown to perceive experiences differently than their non-STEM counterparts. Moreover, the paucity of qualitative inquiry in physics education research introduces uncertainty. The combination of these factors highlighted the uniqueness of this study, which facilitated an open-handed,
authentic exploration of emergent themes. In other words, no one really knew what would happen.
CHAPTER FOUR

ANALYSIS

Introduction

The purpose of this case study was to qualitatively explore advanced physics students’ response to a long-term active learning environment in quantum mechanics. In addition, the study explored active exercises that incited these responses. The research questions were the following:

3. How are upperclass physics students’ experiences shaped by active learning interventions in a core class?

4. Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?

Emerging themes were identified through line-by-line analysis of significant statements during interviews and a focus group, and triangulated through classroom observation, memo notes, and participant feedback. The analysis chapter will briefly describe the study participants, followed by a description of emergent themes. Finally, a summary will be presented that identifies key findings and interesting aspects of analysis results (Komlos, 2011).
Participants

Throughout analysis, individual participant overall engagement response will be noted. The study participants consisted of 13 advanced, or upperclass, students and a seasoned physics instructor. Behavioral engagement was based on their participation in active exercises, along a continuum of active to passive. Cognitive engagement reflects the type of cognition that they regularly demonstrated, along a continuum from high-order to distracted thinking. Affective engagement reflects the arousal level observed, along a continuum from positive aroused to negative unaroused. Individual classroom observation records (Appendix O) provided the bulk of data used to make these summaries, with overall classroom observation records providing a supplementary perspective. In addition, I have included interview quotes for participants that demonstrate a typical response or that reflect an especially insightful viewpoint that they brought (Komlos, 2011). Obviously, interview data was used to summarize their overall attitude to the research. Names have been represented with a letter that does not reflect their name, and gender pronouns have been avoided, to protect the anonymity of the participants, given that no gender-based themes emerged during the study.

Findings

Time Pressure (Theme 1)

There were two themes that emerged in direct response to the first research question that asked “How are upperclass physics students’ experiences shaped by active learning interventions in a core class?” These two themes were Time Pressure and
Vibrancy. While a number of other themes emerged during this research, these two particularly described how student experience was shaped, as a result of the change in environment.

The most repeated critical theme of the intervention, especially during the first month of the study, was Time Pressure. This theme emerged from the addition of activities during and outside of class, as well as the quality of those activities. The addition of active exercises resulted in more variability (hence less control on the part of the instructor) in the pace of the class. In addition, the frequency of class activities sometimes created a more “frenzied” pacing, especially during the first half of the semester. This theme had emotional, cognitive, and behavioral components.

The strongest of the responses came from participant emotional response. The majority of students were frustrated if activities lacked a clear purpose. Because the time pressure highlighted the limited class time, many participants seemed especially sensitive to interventions that were not clearly constructive: “…sometimes it felt like the problems we were doing didn’t really connect with what we were learning. So it made me even more confused about why we were doing it” (L). In addition, students were frustrated if there was inadequate time to complete an activity (or lecture) properly. Here again, it seemed the time pressure amplified participant frustration with not achieving learning outcomes. For example, about half of the students were frustrated if time constraints kept them from summarizing a board activity: “[I] dislike not being able to finish in class

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2 Here and following, a single letter will indicate the identity of a student participant, providing anonymity, while still allowing trends within participants to be noted by the reader.
problems” (Anonymous, 9/1/18). Or, most students were frustrated if the instructor did not complete his lecture notes, and students were either left to navigate the homework on their own, or the homework was edited. Frustration was due to the added challenge of completing homework while inadequately prepared and to the interruption in their learning: “I feel like we are barely covering material…” (Anonymous, 9/20/18). While negative affective aspects of time pressure existed, the time pressure was also reflected by students being more aware of the high value of class time and seemed to enjoy the heightened pace, for example: “I am more excited to be in this class as any other class” (K).

Time pressure affected students’ cognitive engagement, as well. Active exercises required student engagement and performance, often on complex tasks. Time pressure created anxiety that limited perceived cognitive performance for a minority of the students:

I feel like my time when [we are at the board] is a lot more unproductive for me. Because I don’t have the ability to really focus like I normally do when I’m doing homework. I can feel when I’m thinking about a problem, or really trying to figure out a problem, but when we’re at the board, you do or you don’t. If you don’t know it, you can’t really figure it out in that amount of time, or have the ability to reflect about what you’ve learned and then apply it to what you’re being asked to do (L).

In addition, it often limited perceived deeper thinking on concepts for these students: “I feel like it made me do a lot less critical thinking during class…[because] it was almost more stressful to try to keep up than to just zone out and not really pay that much attention” (L). Finally, the time pressure seemed to amplify about half of the participant response to transitions, which inhibited their ability to shift focus from listening to doing:
"You have to shift your mental state," or “I definitely still feel like there were time when I would have rather sat down and continued in the lecture and learning about the topic, rather than getting up to the board to do something” (L). On the other hand, some students reported increased focus in activities, as the transitions felt “… refreshing.”

A minority of students responded behaviorally to time pressure by decreasing homework and video involvement, completion of both being commonly required by the beginning of class. This seemed to be increase as the semester wore on, as fatigue in a very rigorous program set in.

I noticed, not necessarily in this class, a general observation, usually as the semester progresses, at least for me, there seems to be a lull in my attentiveness and curiosity. I don't know what it is, but you get used to the day today, and you're not as excited about what you might learn every day. As opposed to how I start off the semester really curious and enjoying the whole process of school (M).

While homework completion was very high (students seem to be adequately conditioned to commit to and value homework assignments), the video completion rates dropped significantly as the semester wore on. However, it should be noted that changes in video viewership exhibited bifurcated behavior; Some only missed 20%, and some watched only 20%, with little completion rates in-between. Homework completion was tracked during the homework grading process, and video completion was tracked through course management software. Homework completion influenced grades; video completion was voluntary.

In summary, time pressure widely influenced student behavioral, cognitive and affective engagement. For some, aspects of the pressure were debilitating or “dreadful” (N). For others, the pressure helped increase motivation and focus during class. Many
students reported that time pressure decreased as the semester wore on, due to both improved classroom management (essential material was covered), and due to increased familiarity with an active learning model (the pacing seemed less frantic). One student wisely pointed out that “I don’t think we can schedule knowing things…[and] knowing the material is more important than getting through the PowerPoint…” (O) which serves as a reminder that active exercises are just one aspect of the pressures that students feel.

**Vibrancy (Theme 2)**

The most commonly expressed responses reflected the vibrancy of the experience. Common adjectives included “different,” “new,” “interesting,” “engaging,” and “exciting” when describing the active learning environment. In other words, participants found that the environment was more engaging than what they had come to expect from their classes. The effects of this response were observed primarily during class, but were reported outside of class, as well. Students found that the novelty of the approach influenced their behavior, cognition and affect in ways that promoted engagement.

The most common behavioral response related to boardwork activities. Students found that the physical act of getting up broke up the monotony of class and left them more energized. One participant reported that the variability inherent in other types of activities kept him “…on your toes…” (C), which introduced more fun into the class. Others expressed talked about paying more attention. The increased energy associated with this physical movement had broad cognitive and affective implications. Several students talked about the positive impact of hands-on activities on self-regulation—they felt the simple act of trying out a new concept clarified their thinking about it.
Many of the responses to the novelty of the experience were in terms of cognitive engagement. Students found the problem-solving activities to be more enjoyable and mentally engaging—in fact, the word “engaging” was used time after time in describing the class overall. One student even went so far as describing these activities as “playful, and more like fun” (R). Some exercises uncovered unexpected results; Students found them especially “thought-provoking” and found they incited a sense of “wonder” (R). Moreover, active exercises allowed students to connect conceptual with mathematical ideas, sparking curiosity about deeper content. The varied activities changed the pace, which students found cognitively refreshing; They were better able to focus and explore ideas. They were more cognitively relaxed. And, they found the pace variation enjoyable. One student found this characteristic allowed the work to be “less tedious,” resulting in increased focus. Moreover, the tone of the environment moved the focus from passive follower to engaged learner: “Now class is about learning, not just clear presentation” (N). Several students reported feeling like they were in a time warp, where class only lasted a couple of minutes. In summary, one senior succinctly expressed the overall vibe of the class: “There is an energy in the class... [and then class] is immediately over” (O).

While cognitive responses were mostly positive, several students had difficulty with the transitions between activities. They found the transitions could sometimes interrupt thought and waste time. For example, a minority of students reported being distracted from moving onto another activity, while they were still processing the nuances of lecture, because it “…cut off my ability to focus on what we were doing in
class” (L). In this typical example, the participant was frustrated, as (L) felt learning had been compromised because the ability to focus was reduced. Most student response to the difficulties of transitions decreased as the semester continued, finding transitions to new activities easier and less disruptive. In addition, even well-run activities inherently take some time out of class, which can be frustrating in an environment where class time is precious and limited. Moreover, most students also valued the limited breaks during activity transition, as a time to relax and regroup their mental energy.

The novelty of the class influenced most of the students emotionally. “Energizing,” “exciting,” and “fun” were all adjectives that described participant emotional reactions. Almost all participants preferred a more engaged learning atmosphere. They reported that this emotional change increased their motivation and focus during learning. In addition, they reported that they talked abundantly about the course (outside of class) in predominantly positive terms, especially in comparison to other technical courses they had taken. Affective response was also reported before class, as students anticipated what novel activities awaited them in that day’s quantum mechanics class. One student summed up the most positive aspects of the reaction, by reporting that being a part of the class made him feel “… a bit more alive” (Q).

Not all students expressed predominantly positive emotions about the intervention, however. One student, L, found that active learning interfered with the ability to process material effectively. This participant preferred the traditional lecture model, where L could quietly follow: “Having to do an active learning thing in [a well-run lecture-based class] would have been detrimental. Definitely… [Active learning]
would have been disruptive of that flow of understanding during class” (L). Outside of class was the time to review content more in-depth, and to think more critically. L did not see the value of many of the active exercises, feeling they were more like a “show” (L), than providing substantive benefit. L found that they interrupted the ability to think more in-depth about new material during class. Moreover, L was especially adversely affected by poor implementation of active exercises: “I feel like sometimes when we would go to the board and none of us knew what we were doing, it felt a little like we were wasting time” (L). However, L did indicate that minimizing active exercises mitigated negative feelings, even if the lecture model was still preferred.

In summary, all students expressed a variety of strong responses—in all areas of engagement—to the active learning interventions. The variation in activities, combined with novelty inherent in every class, introduced a heightened energy to the class, which— for this group of successful senior physics students— resulted in more curiosity, creative thought, perceived conceptual mastery, and problem-solving fun. The homogeneity of these responses belies a deep intrinsic motivation to learn within this community. Even the predominantly critical response to active learning by L reflected frustration that active learning interfered with the ability to learn. Finally, most students expressed an interest in seeing more active learning exercises in their core classes, even if it wasn’t in the context of a full SEI transformation: prelecture videos, formative quizzes, problem-solving sessions, etc. In other words, students noticed and appreciated active practices.
**Group Activities (Theme 3)**

Three key themes emerged in response to the second research question that asked “Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?” These three emergent themes were *Group Activities*, *Public Work*, and *Individual Work*. Results indicate that participants were most influenced by the *Group Activities*, where interaction with others was a primary factor. In addition, participants distinguished *Public Work* from *Individual Work*, as they described their responses to the activities: The primary factor here was the type of environment present while they worked through challenging concepts.

The most influential exercises could be thematically categorized as *Group Activities*. These activities include any exercises that involved peer interaction, in pairs, threes, or as an entire class. Usually, this occurred within the context of public boardwork exercises, where students would solve problems in groups of 3-4 at the board (such as proofs, conceptual problems, or computation-based problems). There were also seated exercises, where students huddled in groups of 2-3 at their desks, to complete challenges using simulations or structured problems. Most students generally responded favorably, but about half noted several liabilities to a group-based approach. While behavioral response was not significant (other than the act of walking to the board or pulling up a chair), students talked extensively about cognitive and affective engagement.

Cognitively, students reported three main features to group learning: First, almost all found they learned from other perspectives, as the groups often had different opinions
on underlying concepts and problem-solving strategies. In fact, one student lightly complained about not getting enough variety in the groups:

…it's nice to get the different perspectives and talk with different people and kind of change up the groups at times. If everyone has their little group, and it's this normal thing, then I think it loses some of its advantage of being in a group with other people (Q).

Instructor feedback during the exercises provided real-time correction and guidance during this critical time of forming conceptual understanding. The instructor commented on the improved opportunity to guide student thought as it was forming. And, students appreciated the immediate feedback as they explored new concepts. Second, they thought more carefully and deeply about new concepts. The group helped focus on the task, as well as provided an environment where there was no obvious solution, requiring peer discussion, conflict, justification, and negotiation. Working with peers required them to bring their best game, as students understood that the groups succeeded and failed based on their contributions. M expressed this by saying, “They care, so I should care, too.” Third, they were able to refine their thinking patterns, as they discussed new ideas with others who shared similar mathematical and conceptual mastery.

Affectively, most students thoroughly enjoyed group learning: “I enjoy doing group activities and using Phet simulations” (Anonymous, 9/11/18). Most found that working with their peers was fun and engaging. They found that working within a group lowered their stress, as others could contribute, so their mental load wasn’t as heavy. They found that working in groups also incorporated everyone: Effective tasks were open-ended, clearly defined, and challenging, so that all students found that they could make a contribution at some point, and students found that they needed help from their
peers at some point. The optional problem-solving sessions provided the most positive affective responses from those 3-4 students who regularly participated. They found that the optional nature of the time lowered anxiety and promoted a more supportive atmosphere. Students said they were more likely to ask “…crazy questions” (K) or explore more difficult material. A couple of regular attendees remarked that the sessions were essential to their success in the class, both for content review and for affirmation that their questions were welcome (thereby giving them the needed confidence to ask for help from peers and the instructor).

Students also noted liabilities of group work. First, the pace of the group was often set by social dynamics, where the strongest student (in terms of self-efficacy) would direct the group to subsequent steps, even when not everyone understood the concept in question. In other words, students sometimes felt the group moved on without them, which left them unable to contribute on subsequent steps. Worse, the group might move on using incorrect assumptions or strategies, when a more clear-minded student failed to challenge the group. As the semester continued, increased comfort with group activities mitigated these concerns, as students became increasingly comfortable expressing their own challenges or questions. This increased familiarity sometimes affected out-of-class engagement, as well (e.g. more group-based homework corroboration).

Second, several students expressed concern over working in socially uncomfortable situations, where social tensions may run high between participants: "...there is an element of having worked with people in the past knowing their past failures too or their abrasive personality in class..." (B). In this particular group, strong
communal ties and previous positive experiences ensured interactions were predominantly positive, so this concern was purely theoretical. Even so, participants lamented that—even with a quasi-random group assignment—they didn’t have more experience with all of their classmates.

Third, previous experience had shown participants that variation in knowledge or expertise could handicap group progress. Once again, this group did not (in general) experience this type of liability, as participants were (mostly) successful physics seniors. There was an exception: N occasionally found group work "hopeless," when peers demonstrated substantially superior expertise and reasoning, leaving N feeling "useless." Over time, however, N became more comfortable as two things changed—abilities improved, and comfort with the community improved. The unique characteristics of advanced physics students means that they have extensive experience with one another, and they are relatively equally prepared, mitigating some of these liabilities. In addition, the difficulties of dealing with social dynamics in a classroom environment reflect relative inexperience with these types of interactions during the undergraduate curriculum. This model provides a safe, guided approach to working through social difficulties.

Fourth, group work was not favored for all tasks, for all students. Many students enjoyed the conceptual challenges within a group but found calculation-based tasks more appropriate for individual work. In addition, some students preferred more un-structured and student-centered problem-solving sessions to the fast-paced nature of in-class
activities. Finally, one student found less value in group work than in individual work, for all types of tasks.

In summary, group activities were used extensively, and students responded to them most strongly. Students reported improved satisfaction, more complex cognition, and increased enjoyment when they had a structure to learn and explore new content with their peers. While liabilities exist, group-based activities are relatively robust, especially in the unique environment of advanced physics. Moreover, group work seemed to nurture a more collaborative approach to both in-class activities, as well as overall curricular success.

Public Work (Theme 4)

A characteristic of some active learning exercises that impacted student experience significantly was their public nature. These activities involved showing one’s work to the broader class (including the instructor), in real-time. This public aspect had similar responses, whether it occurred in a group or for an individual. The most prominent example of this type of exercise was group-based board work exercises, such as proofs or guided problems, but there were occasional exercises where participants addressed concepts on their own, publicly. The primary aspect of this activity was increasing tension (described by “pressure,” “stress,” “accountability,” or “motivation”) due to students’ work being open to critique before they had settled on a final answer, but factors like feedback and seeing other perspectives also came up.

Behavioral responses to this tension included increased preparation for class. Because students knew that their work might be public, some prepared more thoroughly
than they otherwise might have. In fact, many students reported preparing for quantum mechanics more than they had prepared for other classes during their physics curricula.

This tension also had cognitive impacts—some participants reported increased motivation to succeed, as they knew their peers were watching. Participants described their response to this dynamics in both positive terms (they wanted to outperform their peers, and finish quickly) and negative terms (they worried about failing the exercise, or not quite finishing before others). While this might be categorized as an extrinsic motivation, several students noted that it added a fun, “competitive” dynamic to their class that enhanced, rather than subverted, their strong intrinsic motivation. Some talked about this motivational aspect as “accountability,” as they realized it was their job to be prepared for class, bringing their best self.

However, for a few others, the tension could be better described as “stress” or “anxiety.” In these situations, they found their ability to engage with the material diminished, sometimes catastrophically. One student found that working publicly diminished ability to concentrate on the content itself, introducing anxiety to the problem-solving process:

Most of the times when we were at the board [were stressful] because I feel like I perform a lot better when I’m working as an individual. Or even more in a group-focused setting. Like if we were writing as a group on our papers, then I found that to be not very stressful, because I could work with others and jot down my own thoughts if I had them. But at the board, it was a lot more high-stress, and you had to make sure your group was doing it correctly, especially if we didn’t have a lot of time (L).
A few found that they were unable to maintain focus or address even the most elementary concepts—it was simply too stressful. One of these students found that the public work “killed… confidence” (N).

Another important cognitive aspect of public work was immediate feedback and seeing others’ approaches. Almost all students thoroughly enjoyed instructor support and feedback while they were at the board. They reported that instructor validation or correction somewhat countered any negative effects of social dynamics. His presence provided a type of equilibrium that weighted actual competence, as opposed to self-efficacy. And, the instructor appreciated the opportunity to see holes in knowledge in a timely manner. Moreover, he appreciated the opportunity to engage with students as they were forming mental models, in real-time. In addition, public work allowed students to see how others were approaching the same challenges, resulting in a twofold advantage. Firstly, groups that were stuck were able to look at others’ work to get ideas for next steps, though this happened far less frequently than one might expect. Secondly, students were able to look over other group approaches to see other ways of attacking a challenge. The first advantage helped students in when problems were too challenging, the second enhanced the experiences of students who were succeeding in the boardwork. As a result, well-designed public activities were well-received by most students in the class.

A final cognitive aspect of group work was increased understanding and self-regulation. Even N, who would have gladly seen the boardwork removed from the class, found that group activities helped to “…clarify weak points,” which N could address later, alone. M found that increased interaction with others raised awareness of where
help was needed, so that M could focus on weak areas alone: "For me learning to
verbalize questions keeps me honest about where I am in the material." Finally, students
who enjoyed the boardwork reported increased peer discussion helped them understand
the concept more deeply.

Obviously, the negative stress response had an emotional cost, as well as a
cognitive one. The stress response was notably negative for three students, in particular.
One was highly frustrated that the public nature of some activities, combined with the
distracting nature of the stress, was inhibiting learning, which was very important to the
student. Another student, F, was so adversely affected by being called on in-class (using
the random notecard technique), that the instructor began filtering students upon whom
he would call. While the instructor was supportive and helpful when students had
difficulties in a public exercise, F noted that a chillier climate (than that present during
this research) may have caused real harm. For example, if a student was unable to
answer the question posed, the instructor often re-framed the question in a more leading
way during this course, cultivating a warm classroom climate. If the student was still
unable to respond correctly, the instructor might either give him an easy question, or
allow other students to answer.

Public Work is the component of the active learning experience that changed most
drastically from the beginning to the end of the semester. At the beginning of the
semester, students had pretty much never experienced public board work in college.
Students became more comfortable with these exercises, as they did them more and
more—This was nicely summarized by one student who said that going to the board
became more “normalized” (Q). Participants reported that it wasn't "...as stressful as it was in the beginning..." (R) or even that they were “warming to [public work]” (P).

In summary, Public Work was an essential part of the active experience. The most reported aspects of it were increased tension, though feedback and seeing others’ work were also discussed. For most, the public aspect of exercises positively influenced their overall engagement. For some who initially had difficulty, they found that negative responses lessened in severity, as the semester went on. One student found that public activities had no positive impact on his learning, preferring the lecture model over active exercises. However, the majority of participant response was strongly positive.

**Individual Work (Theme 5)**

The final theme exploring Research Question 2 is Individual Work, reflecting the impact that an active learning approach has on solo work, such as formative quizzes and prelecture videos. The types of responses generally reflected learning aspects related to deep reflection, mostly cognitive in nature. While students generally had positive responses to group work, there were clearly certain aspects of learning that a communal environment did not support, such as deep reflection.

The most noted active exercise was prelecture videos, a supporting activity that enabled seamless preparation for class. While a handful of students found minimal value to this tool, many students valued the videos during class preparation, relating that “Video lectures are great” (Anonymous, 9/1/18). There were two main advantages that were repeated. Students could pause and rewind videos at their leisure, so that they were able to effectively process conceptual knowledge: "Get that repeated understanding" (N).
And, students could "...ask your professor the questions, which is the positive part" (R). Finally, a few mentioned that some particular videos gave them a deeper understanding of the material than they might have had through just the text and lecture—they deepened their understanding.

Individual work also provided an effective path for deep reflection. While a few students found limited value of active learning exercises in facilitating solo reflection, many students noted that the active practices enabled more effective deep reflection. For example, while discussing the simulations, L reflected,

...I think they were really, really helpful, at the beginning, to get some intuitive understanding of how things were going to behave. Which translated to being able to draw pictures of things easier throughout the semester. So I think the simulations really did help like make a lasting impression.

Almost all students emphasized the need for reflection time, and many believed it was where the “real learning” occurred. N found that the formative quizzes were "...tremendously useful," as they gave context to reflect on knowledge by answering: "were you really paying attention" (N)?

In summary, the bulk of active learning practices are communal, in nature. However, students talked extensively about the value of personal reflection time and focused individual work on deep conceptual topics. Characteristics of these individual experiences that were often repeated were lack of time pressure, the opportunity to review material slowly, and occasional discussion with peers.
More Natural Over Time (Theme 6)

While the previous five themes directly address the two research questions, there were other themes that emerged that conditionally addressed the research questions. The direct themes pertain immediately to understanding the respective research question. The conditional themes describe characteristics of the environment that seemed largely due to the influences of an active approach. The first of these themes addresses change in student response to active interventions over the course of the semester. This theme directly addresses differences between short- and long-term intervention and their respective responses.

The change in perception towards an active environment, over the course of a long-term intervention, was a key aspect that drove the design of this research. While the literature is fairly extensive regarding short-term active interventions, the effects of long-term interventions are less known, especially at the advanced level. Will students tire of the approach if it is experienced as anything more than a novelty? Will students become more accustomed to the relatively different approach, especially as seniors who have succeeded in the traditional lecture model? Will they develop a preference for or against active learning over the course of the semester? During analysis, an emerging theme that addressed this question was *More Natural Over Time*, reflecting the increased comfort of participants in navigating a new environment.

While analyzing data, one theme emerged that directly addressed the development of student response from a short-term to long-term intervention: *More Natural Over Time*. This theme reflects the data that indicates familiarity with active learning exercises leads to more natural ways to navigate the new environment, especially as the semester
progressed. Cognitive and behavioral engagements were affected, though the bulk of the responses were affective in nature.

The influence of this increased comfort with active exercises touched almost every aspect of the environment. Time pressure decreased, as students learned to navigate the new approach to class: For example, as the novelty diminished, stressful aspects of the transition also diminished. Q discussed getting used to the transitions: “It might also be that I've grown used to the flow of the whole class itself, and the transitions, going from lecture to boardwork.” One student reported “…warm[ing] to [public work]” (P).

The positive aspects, such as excitement and fun, tended to wax and wane during the semester (as part of the typical semester energy cycle), but they remained positive throughout. Board work, initially “rushed and stressful,” began feeling more “natural,” thereby reducing stress. Several students noted that group work became more effective as peers became more accustomed to working together. This was especially noteworthy amongst students who were more reserved in group settings.

Becoming more accustomed to an active environment had behavioral consequences, as well. For example, reduced apprehension about asking questions was mentioned by a number of students, and reflected in observation notes. As students became more accustomed to working with uncertainty, due to group and public activities, their barriers to engagement—especially with the instructor—lowered. For example, K was “less worried about right and wrong, and more inclined to just ask the question.” Related, the instructor reported increased satisfaction with the opportunity to engage in a
more “collegial” atmosphere. Peers also reported that they were more inclined to work with one another outside of class. This was especially noteworthy for students who had not traditionally worked with other physics students outside of class. On the other hand, a handful of students who did not engage with other students outside of class, did not report the improved aspects of more communal interaction.

In summary, the effects of long-term active learning intervention decrease liabilities often associated with new teaching practices. As students become more familiar with the format of the class, they engage more naturally with active exercises. While there are some behavioral (e.g. working together outside of class) and cognitive (e.g. lessened disruption during transitions) responses, most response is affective. Students are generally less stressed by activities, more comfortable working with their peers, and more comfortable overall engaging in an academic setting.

**Students Differ (Theme 7)**

The first six themes directly address questions raised during the research design process. In addition, there were several themes that emerged that—while not directly addressing the research questions-- are instrumental in understanding the influence of active learning in this case. The first is Students Differ: The types of responses to various exercises varied amongst students, sometimes quite drastically. The second is Community Matters: The character of the community, both in and out of class, strongly influenced student response to an active environment. The third is Hard but Rewarding: The work and energy required to engage during class was higher for both student and instructor, however the effort provided meaningful results. The fourth is Implementation
Difficulties: Initial implementation of active exercises was messy, riddled with errors, and influential on student response. Further discussion of these themes round out analysis of emerging themes of active exercises in this quantum mechanics course.

Not unsurprisingly, student response to active learning exercises varied widely. The most obvious difference was one student’s strong preference for solo work and traditional lecture over communal and active approaches, in contrast to the remainder of the class. However, even amongst students who enjoyed active learning, differences abounded. Some students appreciated activities that resembled a flipped approach (where traditionally lecture-based content is covered outside of class, and team-based activities are conducted in-class), others found them very detrimental. One group of students found the group activities could easily veer off-topic, another group found they provided additional focus. Most students found the in-class simulations to be very useful, a few others found them “weak” and “useless.” Students also differed in their opinions regarding the instructor’s style, which was highly intuitive and exploratory: some found the task of creating structure to be meaningful, others found the non-linear nature bewildering. In each case, participants oriented their statements as a function of personal preference regarding instructor style.

Community Matters (Theme 8)

A second theme that directly influenced qualities of the class, but only conditionally influenced the two research questions, was Community Matters. The majority of the students (11/13) had worked together for the duration of their curriculum. Moreover, they had worked closely in many of their previous classes, which usually
consisted of 8-15 students. Their familiarity with one another manifested itself through clustered seating in the front of the class, informal preclass discussion, working on homework together, and a relaxed tone during group activities. The quality of this community was respectful and familiar. It should be noted that the strength of this group seemed particularly strong, based on both the instructor’s and researcher’s experience, but that traits were not entirely unlike some expressed during the pilot study (a different cohort).

The strength of the community undoubtedly influenced the efficacy of active learning exercises. Several of the students noted that exercises may not have gone as smoothly if there were not positive pre-existing relationships amongst participants. A few students talked about previous poor experiences in group activities, usually when dealing with students outside of their major or with students with whom they had no previous experience. On the other hand, two students who lingered on the outskirts of the existing community found themselves more motivated to join group homework session, as their appreciation of group work increased. In fact, participants commented on the positive role active learning played in building community during the focus group: “I’m less nervous [in class]… Because… during the practice or review sessions… I’m able to talk with everybody” (T).

It is not hard to imagine that strong community is somewhat characteristic for many advanced courses. The cohort in this study have started in a sea of introductory classes and succeeded in their field together. They have struggled together with more advanced topics, and proven their competence to one another, infusing their interactions
with qualities like respect and hard work. They are generally genuinely more interested in mastering material as they are earning a good grade, reflecting a strong intrinsic motivation. Group-based activities provide a sanctioned venue through which students can engage. Moreover, it may strengthen a sense of community, they feel less alone in class, as students realize that their peers are “…struggling right there beside them.” As a result, reluctance to work together may be decreased and the effects of meta-cognitive development may not be restricted to the classroom alone.

In summary, the quality of the community influences many aspects of the course, and this quality is only amplified by the integration of active exercises. The effects of active learning do not stop in the classroom, as a strong community enables the positive aspects of the active environment to pervade the entire community, whether in the form of increased appreciation for a peer’s insight or in the form of stronger relationships. While the strength of this group may be particularly strong, there is no reason to believe that these traits are not common for advanced physics students. Finally, strong community may prove a strong asset to many aspects of an active environment, not typical of introductory classes.

**Hard but Rewarding (Theme 9)**

A third theme that influenced all the participants in the case was increased difficulty and effort, along with increased satisfaction: *Hard but Rewarding*. For the instructor, challenges stemmed from both preparing for class using transformation material, and from managing a new classroom format. For the students, challenges stemmed from unfamiliarity with how to navigate the new format in and out of class.
However, both parties found the improved content mastery and more collegial atmosphere rewarding. It should be noted that quantum mechanics is a particularly difficult topic and requires hard work just to understand at a surface level, let alone at a deep, conceptual level.

Difficulties facing the instructor were twofold: He had to prepare a class using a new set of tools, “…designing the activities…” (Instructor), and he had to manage a class that had more variability combined with less control, “…following the daily plan while allowing time for activities and Q & A” (Instructor). The process of mentally integrating prepared active exercises into the flow of the content required substantial class preparation. While this was not the first time for the instructor teaching this class, the prep time was comparable to building a course from scratch, as opposed to merely refreshing previous content to improve clarity or adjust to curriculum modifications. Second, and possibly more importantly, the instructor had to develop new skills for navigating classroom activities; The tools required for effective lecturing are very different than those required for facilitating engagement and teaching. For example, lecturing puts high emphasis on clarity and accuracy. Circulating between groups at the board requires balancing how much support to give to each group, when to bring everyone together to explain a concept, allowing students to struggle, and summarizing essential points, amongst other things. In other words, the instructor plays a much more nuanced and complex role during these activities, which requires skills not necessarily taught or practiced during faculty development. Fortunately, by using feedback
mechanisms, the instructor was able to identify and implement good teaching practices as the semester progressed.

Students faced difficulties, as well: They had to learn the new skills required for managing course expectations. For example, class preparation was more important and engagement during class was essential. Students were motivated to attend out-of-class optional problem-solving sessions, because they found it supported conceptual knowledge. Activities, simulations, and group work, which provided more nuanced feedback to intuitions. This strengthened student self-regulation. This, combined with strong intrinsic motivation, meant many of the students found themselves working harder on the more difficult concepts. In other words, because the environment enabled them to see their errors more clearly, they worked harder to understand the content.

Both groups found the additional work worth it. The instructor was satisfied with students’ deep conceptual understanding: “I would say rewarding is the performance of the students.” And, he found the more fluid and engaged discussion he was able to have with them rewarding. Students found that the activities gave them additional pathways to understanding, and that the additional time on task helped them understand complex concepts. Several students noted that they wouldn’t have made it through the class, if not for the active learning opportunities. Many students mentioned the curious, apparently contradictory trait of an active class: It required more energy during class, but was simultaneously energizing. As the semester progressed, several students noted that active learning became less energizing, especially during really hard weeks.
In summary, almost everyone in the class found the rewards of improved satisfaction, content mastery, meta-cognitive skills, curiosity, and engagement more than matched the hard work and long hours. Much of the challenge was due to learning to navigate a new format of class, and may be expected to decline as the community’s use of active learning in the classroom improves. However, some of the challenge is inherent to an active environment: Students are faced with their misconceptions, and faculty must develop more interactive teaching skills.

Implementation Difficulties (Theme 10)

A fourth theme describing insights into the case—and one that possibly influenced the class most-- was Implementation Difficulties. While comments regarding effectiveness of implementing a research design are usually reserved for other sections, analysis results are reported here for four reasons. First, Implementation Difficulties were the most significant theme that emerged during the first interviews, coloring most aspects of the student experience. Second, these difficulties are typical to first-time implementation of active exercises in the classroom, hence reflect an aspect of the case that is not unusual or atypical (Chasteen, 2015). Third, these difficulties may especially affect advanced student, because the difficulties were a central component of their transition from predominantly traditional lecture-based models to a more progressive, active model. Fourth, these types of difficulties are expected in any classroom that is dynamic in its approach to a learning environment. In summary, acknowledging and understanding Implementation Difficulties as part of the case is essential to understanding the case in its entirety.
Implementation Difficulties emerged from participant response to operationalization of active learning exercises, most notably during the first 3 weeks. This theme evoked the most adverse cognitive and behavioral responses during the first round of interviews (week 4), both in volume and in intensity. The strength of this theme clouded much of the data analysis, as Implementation Difficulties adversely influenced all aspects of the environment, which in turn, influenced emerging themes. Analysis of interviews, focus group, and anonymous comments indicate that implementation influenced several significant themes. The second interview and focus group provided adequate data to explore emergent themes that were unaffected by Implementation Difficulties, with the luxury of temporal distance.

The first, and most influential aspect of implementation difficulties reflected the study design. The study design followed the SEI model for introductory classes, where active exercises and demonstrations, with corresponding group discussion, dominate classroom time. Students reported frustration with the ineffectiveness of the time in class. “I feel like we are barely covering material and I’m not learning during class” (Anonymous, 9/20/18). They reported that active exercises often lacked value in exploring existing knowledge. Moreover, students reported frustration that they were not learning new content at a challenging pace. The combination of these two characteristics resulted in student anxiety surrounding class sessions, as they felt class time was being wasted, putting them in an increasingly difficult position regarding the amount of content remaining in the class. This tension was further highlighted when the class did not cover adequate material for that day’s homework, and students were required to learn the
material for the homework without previous instruction. This difficulty was addressed by transitioning to the SEI model for more advanced classes.

Second, unfamiliarity with operationalization of best practices in an active environment adversely affected the overall classroom atmosphere. Active exercises were not paced appropriately, often giving inadequate time for in-depth thought, with later synthesis and summary with peers. Or, active exercises lacked adequate structure, so students did not have a clear vision of how to proceed. Discussion of the intent of specific exercises was not regularly and clearly promoted. Finally, the mechanics of using the board, simulation, or other exercise was not seamless (e.g. the simulation would run on some computers, there were not enough markers, etc.). These difficulties were addressed through continual refinement of classroom management strategies.

There were a number of examples of poor implementation of active exercises; Minimal time to answer questions, limited number of participants, irregularly scheduled formative assessments, burdensome JITT homework schedule, and long lectures. It should be noted that none of these difficulties lasted very long, due to the strong feedback mechanisms in place, and the strong communal ties between all participants and the researcher. One difficulty was encountered while giving students the opportunity to answer questions during lecture. First, questions were asked to the entire class, with only 2-3 seconds allocated for response. Instead, questions could have been directed to individual students, and response time could have been extended to 7-10 seconds. Second, questions were generally answered by the same 3-4 students, which gave the
appearance to the instructor of high interactivity. This difficulty was addressed by using cards to call on random students to answer open questions.

JITT approaches to the class were used to address student difficulties with homework (Chickering & Gamson, 1987). However, the tactics of the initial assignment completion schedule was overly burdensome on the students. After one week of trying the schedule, a compromise was found, where students had adequate time for completion, but assignment review could still be completed before class. “The shift in homework policy was confusing at first, but a week of the new schedule should sort that out” (Anonymous, 9/20/18). It should be noted that student response to JITT homework schedule was tepid, with some students preferring weekly due dates rather than more regularly scheduled assignments. However, the instructor found the opportunity to address popular misconceptions and mistakes at the start of lecture very valuable. This difficulty was addressed by modifying the homework due date to better meet student scheduling requirements, but still facilitate review before class.

Finally, the instructor occasionally reverted to a lecture-based approach throughout the semester. In fact, several students communicated some disappointment regarding less active classroom sessions during the course, even if the dominant approach was active.

Summary

Analysis identified a number of themes that addressed the Research Questions and how they changed over time, providing substantive insight into the case. The first Research Question (How are upperclass physics students’ experiences shaped by active
learning interventions in a core class?) was addressed by two themes: *Time Pressure* and *Vibrancy*. The second Research Question (Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?) was addressed by three themes: *Group Activities, Public Work, and Individual Work*. The main theme relating to change in perception—addressing the paucity of research on long-term active interventions—over a full-semester experience was *More Natural Over Time*. Finally, four themes developed that provided additional insights into the case: *Implementation Difficulties, Students Differ, Community Matters, and Hard but Rewarding*. See Appendix Q for a conceptual illustration of relationships between themes and categories.

In summary, ten themes emerged from interviews, a focus group, and supplemental data points. These themes addressed both Research Questions, the influence of long-term intervention, and factors influencing other aspects of the case. These themes provide rich insight into engagement-based responses of advanced student to a long-term active environment.
CHAPTER FIVE

DISCUSSION

Introduction

Following the format of a five chapter scholarly work, this thesis has explored the influence of an active learning environment on advanced physics students’ experiences. Chapter One introduced the problem and the approaches taken to address the research questions. Chapter Two explored literature relevant to foundational active learning theory, as well as topics that directly address an advanced physics active environment, with the intent on putting gaps in literature in context. Chapter Three described the approach that the research has taken to fill in the literature gap. Chapter Four summarized the results of the research, with a special emphasis on emergent themes. Finally, Chapter Five provides an opportunity to interpret the results and discuss aspects of the study that may have a particular influence on developing further knowledge in this field.

Overview

As the value of technical education has increased in today’s technology-based world, more research and attention has been directed towards improving post-secondary STEM education. While the growth in research in physics education and engineering education fields has done much to improve student concept-based outcomes, much is unknown about other aspects of the STEM student experience, such as motivation,
satisfaction, or community, especially for advanced students. To explore this topic, two research questions were developed:

1. How are upperclass physics students’ experiences shaped by active learning interventions in a core class?

2. Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?

Through qualitative exploration of a single case, these questions were addressed through the lens of student engagement, as described by behavior, affect, and cognition.

**Context**

While good strides are being made in improving STEM education practices at the university-level, there is a distinct difference in focus between the fields of education and physics. During discussion about these frameworks with colleagues, the opportunity arose to explore outcomes of progressive practices—within a context broader than simply content mastery—in a quantum mechanics class. Following the pilot study, the opportunity arose to work with the instructor to transform the full course and to research the effects following a rigorous qualitative methodology. The instructor was enthusiastically committed to both the transformation and the research. Besides two graduate students taking the class to inform their research, students were mostly physics majors with high internal motivation. The resulting environment was respectful, curious, scholarly and relaxed, which may or may not reflect advanced classes in other institutions or in other disciplines. My limited experience with other upper-level classes, both undergraduate and graduate, has been consistent with these adjectives at this particular
university. In other words, this case reflected the types of traits one might hope to discern amongst successful upper-level STEM students and their classes.

**Methods**

A case study method was used to explore the influence of active learning on participants and their environment. Two semi-structured interviews provided insight into student initial response and long-term response. In addition, overall classroom observations, pre-lecture video logs and more individual student feedback mechanisms (such as *minute paper* or *muddiest point* exercises) provided a triangulation effect for confirming participant self-report. Finally, individual classroom observations informed additional insights into interview and focus group data, providing a complementarity effect for understanding participant response from a different perspective. It should be noted that the direct interpretation approach exposes the study to influences peculiar to the case under investigation.

A short-term pilot study largely informed methodological tactics and strategies. This phenomenological pilot study qualitatively explored emergent themes, such as stress, satisfaction, and engagement during a chapter covering the *WKB Approximation*. The WKB Approximation, as explored during the pilot study, provides a technique (including the *patch function*) for identifying quantized energy states and their general wave function shapes, when the frequency of the excited state far exceeds changes in the potential well. The difference in results between the pilot study and this research reflect the power of exogenous variables on something as complex and nuanced as a communal culture. First, the participants were different students (though similar in many ways).
Second, the scope of the intervention was different, as the pilot study only covered four class sessions on one topic. Third, my relationship with the class was different, as I was a peer during the pilot study and the GTA during the full study, influencing the case environment.

Fourth, and possibly most influentially, the timing of the intervention was different. With the pilot study, the intervention was conducted towards the end of the course, after strong communal bonds had been forged, and after students had experienced the strange complexity and rigor of quantum mechanics. For the students that were part of the full research case study, the transition to active learning was simultaneous with learning new approaches necessary for success in quantum mechanics. Difficulties inherent to success in quantum mechanics often compounded negative reactions to active learning, and sometimes they were even confused with challenges surrounding the active environment. These responses were most pronounced during the initial stage of the research. In summary, the pilot study provided both insight into the methodological approach, as well as insight into the influence of external factors on student experience, somewhat exposing the liabilities of a direct interpretation study design. It is worth noting here that the influence of these external and often uncontrollable variables introduces significant challenges to quantitative approaches to student experience.

Data Analysis

Data analysis included analysis of both interviews, the focus group, in-class feedback mechanisms, overall classroom observation, and individual classroom observation. All verbal recordings were transcribed verbatim. The NVivo program was
used to group significant statements into categories during the *horizontalization* process (Creswell, 2013a). Categories were interpreted using a recursive approach, until themes emerged that cohesively described various aspects of the case adequately. These themes were then partitioned according to research question that they answered, or other partition where applicable. Finally, special care was taken to preserve divergent views, especially those that were negative or contrary to the majority of the class.

**Results**

*Time Pressure* and *Vibrancy* were the two themes that addressed *Research Question 1*:

How are upperclass physics students’ experiences shaped by active learning interventions in a core class?

Participant response was strong regarding the increased engagement of an active environment in all three aspects—behavior, cognition, and affect. Negative aspects of *Time Pressure* seemed to be largely due to *Implementation Difficulties*, leading one to suspect that physics course transformations with adequate support and training may result in more positive responses to *Time Pressure*.

*Group Activities, Public Work, and Individual Work* were the three themes that addressed *Research Question 2*:

Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?

Group work was definitively the most important factor in understanding which activities were most impactful. Students derived great satisfaction and improved comprehension
from working with their peers, consistent with the literature. What was interesting about this theme was its relevance outside of class, as students found their community strengthened both in and out of class. The environment present during challenges, especially problem-based challenges, largely influenced student response. For some, public work was invigorating, but for others it was paralyzing. These insights into student difference give the careful reader reason to pause before making sweeping statements about the absolute benefit of one type of activity or another.

*More Natural Over Time* was the theme that addressed the longitudinal development of student perception during a long-term intervention. This theme agreed with the literature that suggested student reluctance towards active learning is often due to unfamiliarity. Moreover, by becoming more comfortable with collaborative work, questions, and engaging simulations, students reflected increased use of healthy engagement practices. However, it should be noted that one student preferred traditional environments even after a full semester of active learning; While long-term experiences do seem to improve student response, the relationship is strong but not absolute.

*Students Differ, Community Matters, Hard but Rewarding, and Implementation Difficulties* were the four themes that addressed environmental changes central to the case. Each of these provide insight into ways an active approach influenced the overall environment, hence experience, of the participants. Some interesting features of these themes should be noted. The multifaceted nature of the students highlights the need for varied active approaches, while challenging the trend in STEM education to find an *optimal* approach to education. The influence of community strength in upperclass
students in an active environment has not really been explored, so it was interesting to see it so strongly emerging during this study. Consistent with the notion that learning is difficult, all participants found themselves more focused on the hard work of learning, as well as satisfied with the experience. And, as discussed, department-wide examples of successful implementation of active environments in STEM are available, but effective implementation must be addressed strategically for best results.

This discussion will interpret each of these themes, following a similar structure to that introduced in Chapter 4. The structure will explore Research Question 1, then Research Question 2, then Changes in Perception, and finally Case Insights. While the Chapter Four clearly situated each theme within one of these four sub-sections, the Chapter Five discussion will integrate all applicable themes in each sub-section. For example, relevant aspects of More Natural Over Time will be included in Research Question 1 discussion. In addition, this section will orient the findings within the context of existing literature: Special priority will be given to results that fill gaps within, or contrast from, existing literature. Finally, the results will be summarized.

How are upperclass physics students’ experiences shaped by active learning interventions in a core class (RQ 1)?

The two themes that directly addressed the first research question, “How are upperclass physics students’ experiences shaped by active learning interventions in a core class?” were Time Pressure (Theme 1) and Vibrancy (Theme 2). The combination of these two themes reflect an increase in the intensity and tone of the classroom environment. The most prominent student responses reflected the increased energy of the class. The cause of student response seemed to reflect moving away from a learning
model of transferring knowledge and towards a model that explored the physical world. In other words, an active approach changed the focus of the class from *covering material* (reflective of a passive lecture model) to *mastering content* (reflective of an *Adaptive Pattern* of learning) (Dweck, 1986).

The *direct* effects of an active learning environment on student experience was multi-pronged. For some, it incited a positive excitement while exploring content, through problem-based activities, simulations, or group work. This effect resonates with the literature reporting increased student satisfaction in active environments (Pedra et al., 2015). For others, it strengthened their connection to the phenomenon by providing a concrete personal experience, which in turn informed later exploration of the concept. This effect lies at the heart of constructivism, where learners build knowledge on physical experiences (Dewey, 1938). In addition, the vibrancy of the active environment cultivated more inquisitive approaches to the material, where students were less focused on what was necessary and more on interesting aspects of the phenomenon being explored. This was especially noted during simulations, where students could explore the influence of varied boundary conditions, beyond those outlined by the instructor. As the semester wore on, engagement techniques such as asking questions, peer discussion, and group work became *More Natural Over Time*, facilitating more frequent and less disruptive interactions with the instructor and with new concepts. This effect epitomizes Dewey’s (1903) promotion of the child’s curious fascination with the natural world. Finally, students often found that it was much easier to engage with the material and stay focused for the duration of class. In fact, during sections where passive lectures were
used, students widely recognized the increased difficulty in focusing, as compared to more active class sessions. This effect reflects the literature on student attention span of technical material (Johnstone & Percival, 1976; Khan, 2012d; Prince, 2004).

However, the increased intensity of an active environment had a number of adverse direct effects on students, as well. Because of the addition of active exercises, the time for explaining material was reduced. Both students and instructor felt the increased pressure, which resulted in either covering material in class less in-depth or assigning new content to students outside of class. Both options added substantial time stress, which caused anxiety and frustration. Though this issue was pronounced at the beginning of the course, it lessened by week 12, due to a combination of comfort with the approach (by both students and instructor) and more effective management of active time in class (mostly by instructor). Over time, the increased intensity also introduced a fatigue factor for some students, as the energy required to succeed in an active class was higher than in a traditional lecture.

Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation (RQ 2)?

Three themes directly addressed the second research question ("Which active learning exercises affect upperclass students’ experiences most, due to an active learning transformation?"): Group Activities, Public Work, and Individual Work. While a host of various active learning exercises were implemented during this case, these themes describe the characteristics of exercises that students found most impactful during their experience. Communal aspects of active exercises colored the student experience in many ways, both during class and privately outside of class. Like student response to
Research Question 1, detracting qualities of active exercises decreased as students became more accustomed to the environment.

The influence of Group Activities dominated discussion about directly impactful active learning exercises, whether it was board work, simulations, or problem-solving sessions. Students found that group work enabled them to learn by listening to various perspectives, to think more deeply, and to refine their thinking patterns, demonstrating growth in more relativist perspectives, self-regulation, and complex thought. These attributes resonate with the literature on cooperative and collaborative approaches to learning (Guskey & Pigott, 1988; Marshman & Singh, 2015; Mason & Singh, 2010; Shimazoe & Aldrich, 2010). Moreover, students thoroughly enjoyed working with their peers during class. Finally, the optional nature of the problem-solving session provided a lower risk setting for working with peers and exploring concepts more deeply.

The Public nature of Group Activities meant that participants felt an increased pressure to perform, which for some was invigorating and for others debilitating, reflecting ways in which Students Differ. This characteristic also emphasizes the need for constant feedback between students and instructor, for a supportive classroom environment, and for reminders of why and how certain progressive practices are valuable (S. V. Chasteen et al., 2011; Petersen & Gorman, 2014). It also meant that participants received real-time feedback from peers and the instructor during the knowledge construction process, which was valued by student and instructor alike. These experiences highlighted the value of an interested expert—as opposed to knowledgeable lecturer-- who could guide students at the most critical stage of their learning: knowledge
construction (Dewey, 1903; Khan, 2012b; Lowman, 1996). Finally, the public nature of group activities provided both the weakest students structured support in navigating difficult challenges with their peers, and the strongest students an opportunity to explore deeper and understand peers’ various perspectives.

*Individual Work* was also influenced by *Group Activities*, as well as by other aspects of the active environment. Students found that group exercises revealed weak points in their thinking or calculations skills, and they motivated the students to prepare outside of class (so they could add value while working with their peers). Some of the most precious experience of a student lies in their own knowledge construction. Another critical tool was formative quizzes. Both of these types of in-class experiences informed deeper reflection outside of class, which is the most valuable stage of learning for many of the participants, as it is when they are constructing knowledge and building cognitive models to describe new concepts. In other words, by engaging with the material in a communal and reflective setting, many students found that their deep reflection was more productive. This idea resonates with literature on formative instruction (Chappuis, Stiggins, Chappuis, & Arter, 2012), mastery learning (Kulik et al., 1990), and constructivist approaches to knowledge (Dewey, 1938; Rousseau, 1817). In addition, the prelecture videos provided another source for reflection because they were (relatively) simple and intuitive, they prepared students for class, and they could be paused and rewound to allow time to digest concepts. Finally, while active learning strongly supports many aspects of learning, a classroom model must also acknowledge and support the highly individual nature of knowledge construction and deep reflection.
However, not all responses directly addressing Research Questions 2 were positive. Social dynamics in group work sometimes adversely increased the pace of the group, to the detriment of individuals who did not process as quickly. Also, the direction of problem-based exercises was sometimes determined by the most influential, rather than the most technically competent, although the instructor’s continual presence often provided real-time feedback to correct this issue. This reflects Tonso’s (2014) description of the over-achiever versus the nerd. In this model, over-achievers are students who often are more engaged with public class activities, demonstrate more self-efficacy, and focus more on external displays of mastery. Nerds, on the other hand, are less engaged with the larger community, take quieter roles in group activities, and are more intrinsically motivated to master material—they also tend to more successfully demonstrate conceptual mastery through objective measures. Finally, some students found that the public nature of various exercises introduced too much anxiety, negating any positive impact these exercises might have had. Once again, these responses highlight the need for feedback, a supportive environment, and exercises that are well-designed and flexible.
More Natural Over Time (Theme 6)

In addition to addressing the two research questions that motivated this study, a number of interesting themes emerged that may inform understanding of this case. The theme that most clearly reflected the long-term characteristic of this case was More Natural Over Time. Participants found they were more likely to discuss ideas with their peers, both in and out of class, as the semester progressed. They found it was easier to ask questions for purposes of both clarification and curiosity. They found that active approaches largely restored and cultivated satisfaction with learning (Pedra et al., 2015; Prince, 2004). They reported that their initial negative responses to transitions and more physically active approaches to class reduced in severity, even if they did not disappear altogether.

The instructor grew to be more comfortable with implementing active exercises. In addition, he became more proficient in managing the uncertainty inherent in increased student involvement. Moreover, he refined his activity design and management techniques to more closely align with progressive good-practices (Chickering and Gamson, 1987). Active learning predominantly engaged the students, helped with conceptual mastery, improved their motivation for learning, and increased their satisfaction with the learning experience. Not all activities work for all students, hence instructor sensitivity must guide judicious control and variation of active exercises. And, long-term use of an active approach familiarized students with the process, helping develop a More Natural Over Time engagement in the course.
In summary, the introduction of an active learning intervention in an advanced class revealed a number of thematic elements consistent with physics education research at the introductory level and education as a whole. Participants grew in their familiarity with the environment. Moreover, student and instructor ability to effectively and efficiently navigate the environment grew as well, even if it is difficult to clearly distinguish between these two outcomes. By semester’s end, it did not seem that any aspects of student response changed noticeably differently than what the literature reports about long-term active interventions (S. V. Chasteen et al., 2015; Deslauriers & Wieman, 2011; Pollock, 2009). Nonetheless, seeing student growth through the environment change was personally and professionally rewarding for both the instructor and researcher of the study.

Students Differ (Theme 7), Community Matters (Theme 8), and Hard but Rewarding (Theme 9)

In addition, to themes that addressed the research questions and concerns about the literature gap about long-term active interventions, several conditional themes developed that strongly colored the case, overall. These themes conditionally addressed Research Question 1. *Hard but Rewarding* influenced the case. Many aspects of the active environment required additional effort—on the part of the students and the instructor—both within and without class time. While this additional effort did introduce a fatigue factor, data analysis suggests that the satisfaction involved with this additional work was a much bigger factor in the students’ experiences. Moreover, the instructor recognized the association between the preparation of active exercises and the improved conceptual mastery that students seemed to reflect as a result of them. This
reminds one of claims that learning is both difficult and deeply satisfying (Caine, 1990; Dewey, 1938).

The quality of the classroom community (Community Matters) and individual student differences (Students Differ) also shaped student experience. All participants noted the critical role that healthy community played in their response to active exercises. Fortunately, all the undergraduate physics majors had previous experience working with one another, even if briefly. Their connection as successful students in a shared technical field facilitated and enriched group work. It is important to note that this may be one aspect of the advanced environment that strongly shapes student experience and differentiates it from other introductory environments. Though shared community reflected homogeneity within the cohort, student response differences were seen in almost every aspect of the study. Some found one experience exciting, others found it stressful; some found group work challenging, others found it paralyzing; some found interruptions to the lecture energizing, others found it distracting. It should be noted that though some data was tangentially related to gender, no gender-based thematic, or even discriminant, data emerged in this study. However, all female students were aware that a separate focus group would be conducted to explore the influence of gender on an active classroom environment, so it may be that participants were saving their input on this factor for the focus group.

The idea that Students Differ permeates education theory (R. M. Felder, 2010; Grasha, 1994), and highlights the need for varied activities, feedback, and respect for the complexity of the learning experience (B. S. Bloom, 1956; Petersen & Gorman, 2014).
In addition, participant personality characteristics may play a large role in these preferences. It is entirely possible that those who process their surroundings internally (Introverts, by the Myers-Briggs Type Indicator [MBTI]) may find group-based work troubling, while those who thrive in interpersonal interaction (Extraverts, by MBTI) may find the group activities stimulating. These differences once again highlight the value of a varied classroom environment.

While these differences may frustrate those looking for a turn-key or absolute model for active learning, they highlight the importance of variation in classroom activity. It is worth remembering that student preference is also not the final word—one recalls Dewey’s (1903) lamentation that schooling may so successfully kill students’ curiosity that they actually prefer a passive model. On the other hand, conversation with L indicate a preference for a passive lecture model, not because it promotes shallow understanding (Dewey’s lamentation), but because L has learned effective techniques for navigating content in that environment:

[Active learning] was kind of frustrating because I get much more out of a lecture, so having to deviate away from that was irritating, I guess, because I wanted to spend that entire 50 minutes learning about quantum mechanics and not arguing with my classmates about who was right.

It is worth remembering that a passive lecture model is also subject to this difference in preference. These differences also highlight the need for open dialogue and feedback between student and instructor.

However, unique aspects of the case also substantially influenced student responses to the experience. Their high internal motivation resonated with self-directed and group-based active exercises, in a way that strengthened engagement. Their strong
sense of healthy community positively resonated with group engagement to create a nurturing and rigorous academic environment. Finally, extensive successful experience with the passive lecture model amplified negative responses to implementation difficulties, as well as solidified student preference for a passive model, even over the course of an entire semester.

Several themes conditionally addressed Research Question 2, as previously explained. The effect of community quality on the effectiveness of group work cannot be overstated, as it cultivated an environment of respect and trust, while still encouraging lively discussion. In fact, participants often commented on the increased strength of the community outside of class, due to regular Group Activities in quantum mechanics. This is one area where it is likely that advanced students differ significantly from their younger counterparts, since students have had increased opportunity to work together in an increasingly shrinking community, as they progress through their programs. In addition, Implementation Difficulties colored student response to active exercises, as it took several weeks to find a good balance of exercise time and lecture time. This was particularly true for Group Activities, as the board activities initially had unclearly defined scope and direction. While open-ended Group Activities eventually provided an effective range of challenges for the most challenged and the most capable students, identifying how much uncertainty students could navigate took time to figure out. While many comments about the most impactful active learning exercises were common amongst participants, for most other exercises Students Differed. Some students thoroughly enjoyed the problem-solving sessions, others seldom attended; Some students
found group work deeply rewarding, others preferred solving problems privately. The preference variation between students seemed mostly aligned with their view of how they learned best. This aspect of the research highlights the varied ways in which students thrive, and warrants further research, as no coherent structure behind these preferences could be clearly deduced. Finally, engaging with active exercises increased cognitive load during class, which was noticed by many, especially late in the semester (Sweller, 2011). However, the clear majority of participants found the extra effort worthwhile: Active learning was *Hard but Rewarding*.

In summary, active exercises impacted students in ways that largely reflected the literature on progressive practices. Participants valued various aspects of active exercises: collaboration (Shimazoe & Aldrich, 2010), real-time feedback (B. Bloom, 1968; Kulik et al., 1990), understanding other perspectives (Moore, 1994), and improved reflection (Grossman, 2008). Moreover, student response was largely positive to almost all active exercises that were implemented, reflecting student preference for engagement during learning. This is one area where the large spectrum of progressive practices introduces many options for an active learning environment, further obfuscating attempts to quantitatively identify the optimal class experience. Finally, it should be noted that ineffective implementation of active learning seemed to be amplified amongst participants with a long history of success in passive lecture models, consistent with critiques of a passive learning found in *The Child and The Curriculum* (Dewey, 1903).

On the other hand, student response about impactful exercises reflected some unique aspects of a STEM-based advanced environment. As discussed, the strength of
the community—a factor largely dependent on previous student shared experience—played a critical role in both the effectiveness of Group Activities and student satisfaction in peer learning. An active environment also provides a venue through which quantum concepts were tested and explored, rather than just discussed—an essential idea in constructivism. This opportunity is particularly important in technical fields, where clear thinking is important for mastery. In addition, participants continually reflected a strong internal motivation to master content and explore concepts, often regardless of class-specific expectations; One can imagine this trait is largely due to a history of success in a technical field that they find personally exciting. Hence, participant descriptions of impactful exercises were largely consistent with existing literature, but unique characteristics of the advanced physics environment influenced their responses, as well.

Implementation Difficulties (Theme 10)

Implementation Difficulties, Theme 5, clouded the class environment primarily during the first 3-5 weeks of the class. These difficulties introduced additional anxiety and frustration with most students. Because of the compounding influence of these difficulties (Petersen & Gorman, 2014), multiple aspects of the students’ experiences were negatively affected. A confluence of a poor active model, difficult content, instructor style, and unfamiliarity with an active environment resulted in adverse cognitive and affective responses. By heavy use of feedback mechanisms, adjustments were made to all most aspects of implementation, so that successful operationalization was well on-course by week four.
Analysis uncovered a number of sources for this theme, but exploration and discussion of these sources are essential for understanding the case. First, the research design planned on following the more popular SEI model for introductory classes, rather than the more appropriate SEI model for upper-level classes. I unsuccessfully attempted to implement the SEI model for introductory classes, rather than the less interactive upper-level model. The SEI model for introductory classes is founded on activities and discussion, with minimal (if any) lecture time (Deslauriers et al., 2011). While the reasons for this decision were well-founded, more trust in the work of the SEI community would have been well-placed. Students found that the constant transitions between activities was too distracting to maintain focus on one concept. Students also missed the type of explanation and insight that lecture provided. As a result, participants reported that they were simultaneously wasting time in class, and missing valuable insight that class had historically provided.

Once the SEI model for upper-level courses was implemented, participants seemed to find the environment more satisfactory. The revised approach still provided the opportunity to explore quantum phenomena through simulations or group work. However, there was extensive time devoted to explication of new concepts, and students were comfortable interrupting lecture to ask questions. Finally, the nature of quantum mechanics means that the bulk of learning is not in observation of phenomena, but in manipulation of concepts.

It is suspected that the issue may stem from the relatively complex nature of knowledge construction in quantum mechanics, as compared to introductory physics
classes. Because quantum requires a great deal of base knowledge, the cognitive load is high. In addition, connecting quantum concepts requires a great deal of deep knowledge, resulting in knowledge construction that requires focus, concentration, and time (Chasteen et al., 2015). In other words, following Kolb’s model, more time is required in reflection about quantum concepts than might be required for other topics. While lecture provides guidance on basic knowledge construction, its real value may be elsewhere—it may be that lecture provides a scaffolding for students to follow as they make sense of quantum concepts outside of class. In other words, the in-class lecture may show students the big ideas, and it may give them a template for constructing their own knowledge outside of class (Carr and McKagan, 2009).

Second, unfamiliarity with operationalization of best practices in an active environment adversely affected the overall classroom atmosphere. A number of active learning good practices took time and practice to implement fully. While this is typical for instruction in any new approach, these mistakes are worth noting to provide transparency. Moreover, their effect on student response seemed amplified, due to the presence of an active environment (Shimazoe & Aldrich, 2010). Once again, strong feedback with students facilitated correction. This is a recurring theme in the literature, and an essential component of a successful transformation, especially where institutional support is weak (Shimazoe and Aldrich, 2010; Chasteen et al., 2012).

For example, initial class participation followed a typical model of asking the class a question and calling the raised hand. By reviewing the number of interactions, tracked by person, one could see the inequity of interaction. One tool that helped address
these difficulties was the use of index cards to randomly call on students. Moreover, by re-shuffling after every question, students could not tune out after answering a question.

Or, another example is daily formative quizzes: Gray and Madson (2007) suggest short quizzes at every class session. In this case, it was difficult to give short quizzes that had added value, simply due to the time required to complete the complex tasks common in quantum mechanics. While weekly quizzes were acceptable, an ideal solution would be a 30-60 second quiz during every class. While some students found them exceptionally helpful, they were intermittent, which was a barrier to student behavioral focus in getting prepared for class daily. It should be noted that this practice was one of the most influential in class preparation, hence improvement in conceptual understanding, during the WKB pilot study.

An Implementation Difficulty was regression of the class to traditional lecture. This seemed to be due to a combination of some material (quantum formalism) being difficult to explore using active techniques, and due to the high time demands of the intense semester-based time schedule. The occasional use of the easier lecture-based model may reflect the difficulties of implementing a novel approach without institutional support.

In addition, lack of institutional support meant participants had limited resources while identifying solutions to these new problems. One aspect of effective implementation emphasized by CWSEI is the need for strong team-based approaches and departmental support to physics course transformations. The literature indicates that a more team-based approach would bring clarity and focus to exercise design and
implementation, as well as overall curricular design. And, collaborative classroom training, based on progressive approaches, would support more effective classroom management techniques, which vary substantially from those required in passive lecture models. Finally, department-level support for implementing innovative practices might include expert instructional staff support, especially during first-time active courses or first-time active instructors.

All of these dangers were foreseen during the research design process. While steps were successfully taken to mitigate their effects, the ambitious scope of the project opened the research to the effects of implementation difficulties. In fact, this experience highlights the widespread suggestion to implement classroom changes slowly (Gray & Madson, 2007) and to develop a systematic, team-based approach to physics course transformations (S. Chasteen & Perkins, 2014; S. V. Chasteen et al., 2011).

Summary. In summary, Students Differ, Community Matters, Hard but Rewarding, and Implementation Difficulties were four themes that described important aspects of the case. As already discussed, much of these characteristics are typical of active environments and learning theory overall. While variation amongst students (Student Differ) did not seem particularly alarming or unusual in this group, the peculiar nature of an advanced physics course seemed to strongly influence the remaining themes. Strong community (Community Matters), presumed to be present amongst many upperclass students due to their shared experiences, is amplified in an active environment, possibly providing opportunity for enrichment through Group Activities far beyond what introductory students experience. Both student and faculty were committed
to mastery and exploration of the course content, motivated less by meeting a criterion as by the sheer satisfaction of learning about the natural world. This, combined with a strong work ethic, cultivated a highly rewarding experience for many participants (*Hard but Rewarding*). Finally, student responses to *Implementation Difficulties* were largely typical. However, their high internal motivation amplified their frustration when active exercises impeded their learning. In other words, it seems complications with effective implementation may especially problematic with the most experienced and successful students.

**Recommendations for Practice**

This section provides recommendations for instructors and administrators intent on implementing active exercises in an advanced STEM environment to support their students’ growth. It is hoped that this study provides four critical take-aways. First, implementation of active exercises are largely effective in advanced classes, as well as introductory classes. While some aspects of student experience may differ, the advantage that an active approach provides helps most students, and does not seem to adversely affect any, regardless of standing in an academic program. This recommendation aligns with existing literature (Prince, 2004). Second, an active environment benefits both conceptual mastery, as well as other less-measured aspects of the student experience, which is an important view for those instructors who care for their students as scholars and humans, rather than simply physicists. For example, participants report stronger self-regulation, higher satisfaction, and better conceptual mastery. Third, there is no secret recipe for optimal learning. While the promotion of active learning approaches may
imply that more is better, the literature and this study’s results have indicated that is not
the case (Pedra et al., 2015). Because of the various characteristics of every institution,
field, and student, students will find active exercises beneficial in different ways. So,
pick a favorite active exercise and try it out. What is important is to implement
progressive practices—maybe just one or two in a week—in incremental steps that fit
your style and comfort. Hold these changes loosely, support your students, listen to
feedback, and continually improve. This take-away is also applicable for instructors with
experience implementing active exercises. In fact, this may be an area where further
research explores the impact of various strategies, and provides instructors with sample
curricula of varied styles. Keep experimenting and listening to your students, as the good
may be the enemy of the best. Fourth, full course transformations are complex
procedures that require a wide breadth of expertise and considerable resources. New
curriculum must be developed, assessment procedures must be refined, active exercises
must be identified (and vetted and refined), student expectations must be addressed, close
feedback with students must be cultivated, education and technical expertise must be
integrated during the classroom session, out-of-class activities must be managed, and
daily classes must be prepared. Progressive interventions cannot be reasonably expected
to thrive without department- or institution-level support, such as faculty teaching teams,
course buyouts, or education support staff (of course, in addition to graduate student
support often required for effective implementation of a standard physics course).
Characteristics of successful programs include program-wide support, education
expertise, and a team of colleagues working together (S. Chasteen & Perkins, 2014).
It is also worth briefly summarizing insight that the instructor of this study provided about the experience, from his point of view. First, the work required was voluminous, especially for those faculty that strive to cultivate a class experience that provides clarity and insight into their students. Second, student feedback was essential to overcoming the obstacles that grew from trying new things in the classroom. Third, a successful classroom transformation requires the support of education experts in developing curriculum and operationalizing new teaching techniques. Fourth, improved student content comprehension, as well as a heightened collegial connection with the students, provided a source of satisfaction during the teaching experience. Finally, student response varied widely in optimal integration of active practices—some preferred more progressive activities and others preferred more traditional. This was consistent with the instructor’s view that active exercises and lecture-based approaches are two important aspects of a well-run and well-received course design.

Recommendations for Future Research

This section provides recommendations for scholars intent on exploring the gap in existing literature more fully. While this research design explored basic influences that shaped student experience in an upper-level active STEM environment, it also raised a number of questions that may be answered through future research:

- How generalizable are these results? The qualitative nature of this research provides a rich exploration of this particular case. However, to further understanding of student experience, more generalizable research methods must be implemented. For example, behavioral and affective survey
instruments may provide a better quantitative understanding of the advanced student experience.

- How do underrepresented students respond to active environments in advanced STEM classes? While a large swath of literature addresses underrepresented student experience in college (Astin, 1993), and in the STEM field (Lichtenstein et al, 2014), little research has explored upperclass STEM minority experience. Because of the substantial influence of communal quality on student response to active exercises, and the unique characteristics of community for advanced students, it is likely that underrepresented groups (minority or female students in physics) have different experiences in an active learning environment than their majority counterparts (Chasteen et al., 2012).

- What impact does a program of study have that has fully integrated progressive practices on student engagement? While some research has shown lasting impact of active learning from course to course (Pollock, 2009), and the SEI model provides a template for effective implementation, far more research is needed to unpack the far-reaching impact of progressive approaches, especially as a result of long-term interventions.

- Do graduate students have similar responses to active approaches? If so, what are common trends, and what are characteristics that distinguish them from their undergraduate counterparts? While some research has shown similarities between graduate student meta-cognitive skills and epistemological
frameworks as their undergraduate counterparts (Carr and McKagan, 2009; Mason and Singh, 2010), other research has shown that graduate students do have more complex thinking patterns (Singh and Marshman, 2015). The effects of an active learning environment on these students may be unique, due to these influences.

- How can active approaches facilitate STEM student growth during their college experience? In other words, do more group activities cultivate stronger communities later in a college program? Or what types of active exercises are most effective at scaffolding better self-regulation during student development? This study suggests that previous communal experience, community quality, instructor interaction may strongly influence student affective, and even cognitive, growth. While a veritable library of research explores student growth (Astin, 1993), and there is growing literature that explores STEM student experience (Johri and Olds, 2014), the influence of in-class learning environments on student development needs more exploration.

- What are good approaches for developing both conceptual growth and computational strength? While active approaches have demonstrated improved conceptual understanding, computational skills do not seem to benefit (Singh and Marshman, 2015). So, what techniques cultivate both of these skills in courses where both are required (such as quantum mechanics)?
Conclusions

This qualitative single case study has addressed student response to active learning environment and the exercises that were most influential. Through two interviews, a focus group, and supplemental data collection, ten themes emerged that described the case. *Time Pressure* (theme 1) reflects the increased intensity of the class, as students were required to move from experience to experience within a limited time. *Vibrancy* (theme 2) was a related theme, as students found the active approach new, interesting, and invigorating. *Group Activities* (theme 3) reflected the influence of group structure on student response to specific active exercises. *Public Work* (theme 4) and *Individual Work* (theme 5) described characteristics of problem-solving environments. *More Natural Over Time* (theme 6) summarizes the development of student response during the long-term intervention. *Students Differ* (theme 7) describes the influence of student heterogeneity in an active environment. *Community Matters* (theme 8) explores the impact pre-existing and new community ties have in the classroom. *Hard but Rewarding* (theme 9) addresses difficulties surrounding student transition, instructor preparation, and ongoing high engagement. *Implementation Difficulties* (theme 10) reflect aspects of this case stemming from (productive) mistakes and their consequences. Thirteen students and one instructor provided multifaceted insight into how active learning changes the classroom environment. Moreover, this case study has begun an exploration into a gap in the literature where the influences of long-term active learning in an upper-level environment is not clearly understood, in terms of student cognitive, affective and behavioral engagement.
In summary, qualitative inquiry has enabled a rich exploration of the student experience, far beyond what quantitative assessment of conceptual mastery provides. By analyzing a semester-long course, the case study identified prevalent themes that influenced student experience, in terms of cognitive, affective, and behavioral engagement. This research has found that advanced physics students largely responded in ways that agreed with the literature on educational theory, cognitive theory, and active learning.

However, this research also uncovered interesting aspects of the advanced STEM environment that may instruct future work that cultivates richer and more effective environments for students in this stage of their program. Mainly, introducing active exercises evoked a sense of wonder and deep curiosity with quantum mechanics that passive lectures fail to do, largely due to student deep intrinsic motivation. Group activities provided a scaffold for peer instruction that thrived in the context of a strong scholarly community. Probably due to student experience, they were able to discern and appreciate the value that simulations and other models of phenomenon brought to later knowledge construction, especially given the highly complex and technical nature of upper-division courses like quantum mechanics. Finally, these successful students demonstrated a strong work ethic, that combined with interesting exercises, to produce a rewarding learning experience.

These results provide an interesting lens through which to understand student experience of active learning in a semester-long case study of quantum mechanics. But the results also paint a far richer picture of the benefits of active learning than impressive
changes in conceptual mastery. It is hoped that a broader view of the student experience and of the value of education may instruct further work in cultivating an institutional environment that promotes and cultivates all aspects of student growth.

In conclusion, active learning changed the environment of the physics classroom in four influential ways. First, and most notably, integrating new classroom practices introduced difficulties, as student and instructor adjusted to new norms. It is worth remembering that this aspect of the study is characteristic of any risky endeavor, where the sheltered norms of tradition are abandoned in favor of progressive approaches. With a steady and industrious approach, that respects student diversity and feedback, these obstacles can be overcome. Second, on the other side of these obstacles, student excitement grows, curiosity thrives, and conceptual mastery improves, even if-- possibly because-- effort increases: As one student reflected, while thinking of the joy of exploring new quantum concepts: “…this is why I got into physics in the first place.” Third, students are complex beings, with a multitude of various-- and sometimes conflicting-- characteristics. While focusing on conceptual mastery neatly reduces outcomes of the student experience, focusing on their overall growth seems to reflect the reality of their true experience. Various types of activities that respect student personality and learning preference, more human approaches to the classroom that involve feedback and community-based experiences, and an assumption of strong intrinsic motivation are approaches that seemed to effectively cultivate overall student growth in an upper-level quantum course. Finally, while active learning is currently a popular buzzword in STEM education, active approaches only address limited aspects of the student experience. A
truly progressive and effective learning environment promotes, cultivates, and supports all aspects of student development (e.g. all four stages of Kolb’s Experiential Learning Cycle, motivation, satisfaction, modeling expert-like thought, and conceptual mastery) through thoughtful, informed, and strategic planning and implementation.
REFERENCES CITED


Komlos, B. Z. (2011). *Constructing a Model of Success for First-Year Native American College Writers*. (Doctorate of Education), Montana State University, Bozeman, MT.


Vredevoogd, W. J. F. a. J. (2010). The future of learning: 12 views on emerging trends in higher education: on behalf of our campuses, we need to seek out change; to be more flexible, more thoughtful, and more open to student decision making; and to build outcomes measurement feedback into integrated planning. *Planning for Higher Education, 38.2* (January - March 2010), 5.


APPENDICES
APPENDIX A

CONCEPT MAP, RESEARCH DESIGN
Dewey / Piaget & cognitive constructivism

Theoretical foundation for

Evidence-based practices

Cognitive Science

Motivation

Cognition

Structured homework

Interactive Engagement (Hake)

Modifications to SEI Model, such as formative assessment

Mastery-based learning (Bloom)

Assessment & feedback in learning

Peer-to-peer Instruction (Mazur)

Active Learning

Evidence-based practices

Practices operationalized for post-secondary STEM in SEI model

SEI Model

Provides template for effective implementation

Modifications to SEI Model, such as in-class practice.

Student Experience

Cognition

Behavior

Emotion
APPENDIX B

CONCEPT MAP, LITERATURE REVIEW
GAP IN LITERATURE, STUDENT ENGAGEMENT IN ADVANCED ACTIVE PHYSICS ENVIRONMENT
APPENDIX C

KOLB’S EXPERIENTIAL LEARNING CYCLE
Concrete Experience

Active Experimentation

Reflective Observation

Abstract Conceptualization
APPENDIX D

KOLB’S EXPERIENTIAL LEARNING CYCLE AXES
Concrete Experience

Concrete

Active Experimentation

Active

Abstract

Abstract Conceptualization

Reflective Observation

Reflective
APPENDIX E

COMMUNITY OF PRACTICE MODEL
Legitimate Peripheral Participants

Participating Members

Core Members, Experts
APPENDIX F

FOUR PILLARS OF BRAIN-BASED LEARNING AND EXPERIENTIAL LEARNING
Concrete Experience

Gathering Data

Active Experimentation

Testing

Reflective Observation

Reflection

Abstract Conceptualization

Creating
APPENDIX G

STRESS VERSUS COGNITIVE PERFORMANCE
Stress-Performance graph.
APPENDIX H

SAMPLE LESSON PLAN
<table>
<thead>
<tr>
<th>Activity</th>
<th>Purpose</th>
<th>Time</th>
<th>End Time</th>
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<tbody>
<tr>
<td>Warmup-- Homework review</td>
<td>Transition into class</td>
<td>5</td>
<td>2:15</td>
</tr>
<tr>
<td>Review quiz [4.1 PP quiz], with review</td>
<td>review of spherical material.</td>
<td>8</td>
<td>2:23</td>
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<tr>
<td>WRB lecture-- basics of XYZ sep of variables, and how SE changes. [4.1PP 3D intro, slides 1-6].</td>
<td>New material</td>
<td>12</td>
<td>2:35</td>
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<tr>
<td>Muddiest Point from today on content-- if adequate time</td>
<td></td>
<td>3</td>
<td>3:00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>50</strong></td>
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</table>
Spherical Quiz

1. Draw the coordinate frame for spherical Coordinates, showing R, theta, and phi.

2. Write the spherical coordinate expression for An infinitesimal unit of volume (d3r).
Ch 4 Schrödinger Eq. in 3-D

The basic Schrödinger equation in 3D:

\[ i\hbar \frac{\partial \Psi(\vec{r}, t)}{\partial t} = H \Psi(\vec{r}, t) \]

with

\[ H = \frac{1}{2m} \left( \hat{p}_x^2 + \hat{p}_y^2 + \hat{p}_z^2 \right) + V(\vec{r}, t) \]

The components of the momentum operator:

- \( \hat{p}_x = \frac{\hbar}{i} \frac{\partial}{\partial x} \)
- \( \hat{p}_y = \frac{\hbar}{i} \frac{\partial}{\partial y} \)
- \( \hat{p}_z = \frac{\hbar}{i} \frac{\partial}{\partial z} \)

Or using the gradient operator:

- \( \vec{p} = \hbar \vec{\nabla} \)

The Laplacian

\[ \nabla^2 = \nabla \cdot \nabla = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \]

So we can write the Schrödinger equation as

\[ i\hbar \frac{\partial \Psi(\vec{r}, t)}{\partial t} = \hbar^2 \nabla^2 \Psi(\vec{r}, t) + V(\vec{r}, t) \Psi(\vec{r}, t) \]

3D Wave function: \( \Psi(\vec{r}, t) = \Psi(x, y, z, t) = \Psi(r, \theta, \phi, t) \)

Probability density (m³):

\[ d^3r = dx dy dz = r^2 \sin \theta dr d\theta d\phi \]

The Laplacian in spherical coordinates:

\[ \nabla^2 \Psi = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial \Psi}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial \Psi}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 \Psi}{\partial \phi^2} \]

The Time-Independent Schröd. Eq. in 3D

If the potential \( V \) is independent of \( t \), there is a complete set of stationary states \( \psi_n \)

\[ -\frac{\hbar^2}{2m} \nabla^2 \psi_n(\vec{r}) + V(\vec{r}) \psi_n(\vec{r}) = E_n \psi_n(\vec{r}) \]

and \( \psi_n(\vec{r}, t) = \psi_n(\vec{r}) e^{-iEt/\hbar} \)

We need to solve the 3D TISE for the eigenstates of \( H \)

\[ \left[ -\frac{\hbar^2}{2m} \nabla^2 + V(\vec{r}) - E \right] \psi_n(\vec{r}) = 0 \]

For any initial state, the solution for \( t > 0 \) is

\[ \Psi(\vec{r}, t) = \sum \psi_n(\vec{r}) e^{-iE_n t/\hbar} \]

where \( \psi_n = \int \psi_n^*(\vec{r}) \Psi(\vec{r}, 0) d^3r \)
Separation of variables: x, y, z

If the potential is time independent and is the sum of potentials that depend on x, y, and z,
\[ V(\vec{r}) = V_x(x) + V_y(y) + V_z(z) \]
Then we can use find separable solutions:
\[ \psi_{\text{seis}}(x, y, z) = X_k(x) Y_l(y) Z_m(z) \]

First, write the Schrödinger’s equation as
\[ -\frac{\hbar^2}{2m} \nabla^2 \psi + V_x(x) + V_y(y) + V_z(z) = E \psi \]
\[ \psi(r) = 0 \]

Example: 3D Anisotropic Harmonic Oscillator

For particle of mass m in a potential
\[ V(\vec{r}) = \frac{1}{2} k_x x^2 + \frac{1}{2} k_y y^2 + \frac{1}{2} k_z z^2 \]
\[ \omega = \sqrt{\frac{k}{m}} \]
\[ X_k(x), Y_l(y), \text{ and } Z_m(z) \text{ are independent SHO solutions} \]
\[ X_k(x) \text{ has eigenvalues } E_k = (k + \frac{1}{2}) \hbar \omega \]
\[ Y_l(y) \text{ has eigenvalues } E_l = (l + \frac{1}{2}) \hbar \omega \]
\[ Z_m(z) \text{ has eigenvalues } E_m = (m + \frac{1}{2}) \hbar \omega \]

The stationary states of the 3D anisotropic HO
\[ \psi_{\text{ho}}(x, y, z) = X_k(x) Y_l(y) Z_m(z) \]
with energies \[ E_{\text{ho}} = E_k + E_l + E_m \]
If \[ k = l = m = k \]
\[ E_{\text{ho}} = (k + l + m + \frac{1}{2}) \hbar \omega \]
Note that if \[ k = l = m = k \]
\[ V(r, \vec{r}) = V(r) \]
APPENDIX I

DATA INSTRUMENT TABLE OF SPECIFICATIONS
<table>
<thead>
<tr>
<th>Research Question</th>
<th>Data Instrument</th>
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<tbody>
<tr>
<td>RQ1: Response</td>
<td>Interview 1: Q2, Q4, Q5, Q6, Q7</td>
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<td></td>
<td>Interview 2: Q1, Q3, Q4, Q5, Q6</td>
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<tr>
<td></td>
<td>Focus: Q1, Q3</td>
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<td>Class and Individual observation</td>
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<td>Muddiest Point</td>
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<td>RQ2: Exercise</td>
<td>Interview 1: Q3</td>
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<td>Interview 2: Q2</td>
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<td>Focus: Q2, Q4</td>
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<td>Class observation</td>
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APPENDIX J

RESEARCH STUDY TIMELINE
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<th>Spring 2017</th>
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<th>Fall 2017</th>
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<td>Full Course Transformation</td>
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<tr>
<td>Long-term Intervention</td>
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<tr>
<td>Data Collection</td>
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<tr>
<td>Interview 1</td>
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<td>Interview 2</td>
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<tr>
<td>Focus Group</td>
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<tr>
<td>Data Analysis</td>
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<td></td>
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<tr>
<td>Results</td>
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</tr>
</tbody>
</table>
APPENDIX K

INTERVIEW ONE PROTOCOL
Interview 1 Transcription Master

Brett:

Today, we'll be exploring your experience in quantum mechanics this semester, as part of an active learning environment. As a reminder, this research is part of my thesis, which is to explore the student experience of an active learning environment in upper-level quantum mechanics. While more 'student-centered' approaches to learning are becoming more prevalent, there is still much we do not know about the student experience, especially in unique areas, such as upper-level STEM courses. For example, students in your position have shown themselves to be highly successful. The content is just plain difficult. And, it is very unusual to see explicitly quantum behavior in the world around you-- unlike mechanics, for example. These contribute to a unique learning experience.

To make sure we're on the same page, I'd like to take a moment to briefly describe the concepts we'll be discussing. First, and most importantly, I'm looking for your perception of the class. What has your experience looked like? I would encourage you not to think about a 'right' answer, but rather about the most 'honest' answer. The goal is not to build a case for or against active learning, but to really explore and understand your experience. Second, active learning. We define active learning as an approach that uses exercises, in which students participate, during learning. For example, board activities or simulations. Third, I'll ask questions about your patterns of thinking- we sometimes refer to this as cognition, your feelings-- we sometimes refer to this as affect, and your behavior. Fourth, we sometimes use the word ‘impactful’ in these situations. In layman’s terms, this describes those times when something affects or influences you, in action, feeling, or thought. Fifth, my focus is on anything said or done as part of the class-- homework, review sessions, class time, etc. You are welcome to discuss it all. Sixth, whatever happens during the interviews is completely anonymous-- so feel free to talk about anything you want. The Instructor will have a chance to read the final paper, but all identifiers will be protected. For example, your name will be represented by a letter not identified with your name. Finally, I should remind you that your participation is completely voluntary-- if you want or need to leave at any time, you may. Do you have any questions? Great, let's get started.

Preliminary Questions:

1. Age?

2. Major?

3. Status in curriculum?

4. How much of curriculum at MSU?

5. Plans after graduation?
Interview Questions:

1. On a scale of 1 to 5, one being the least and five being the most, how much have your other physics classes implemented active learning exercises, like peer instruction, simulations, etc.?
   1  2  3  4  5
   a. If 1, have you had any active learning experiences within physics?
   b. If 2-5, what types of active learning experiences have you had?

2. What are up to three significant adjectives that you would use to describe the first couple of weeks of active learning in quantum?
   a. Which event best represented that experience? (for each adjective in #2)

3. Which activities seem most impactful?
   a. How was that activity impactful (for each activity in #3)?

4. Are there any aspects of the active environment that seem detrimental or detracting to the class?
   a. If so, which ones?
5. As a result of active learning in this class, have you adjusted your behavior (such as attendance, participation, or out-of-class work) in any noteworthy ways?

a. If so, can you give me an example of how you’ve adjusted?

6. In education, we sometimes talk about cognitive concepts, such as reflecting on ideas, problem-solving, focus on conceptual understanding, or just simply wanting to learn. Reflecting on these types of concepts, do you have any noteworthy reflections that you can share, that were influenced by active learning?

a. If so, can you give me an example?

7. Sometimes in education, we talk about feelings, like ‘frustrated,’ ‘stressed,’ or ‘intrigued.’ Can you tell me some of the feelings you’ve had, due to the active learning approach in this class?

a. If so, can you give me an example of when you felt this way?

8. Is there anything else you want to tell me?
APPENDIX L

INTERVIEW TWO PROTOCOL
An exploration of student response to an active learning environment in an upper-level Quantum Physics course

Interview 2 Protocol

Introduction:
Today, we'll be exploring your experience in quantum mechanics this semester, as part of an active learning environment. As a reminder, this research is part of my thesis, which is to explore the student experience of an active learning environment in upper-level quantum mechanics. While more 'student-centered' approaches to learning are becoming more prevalent, there is still much we do not know about the student experience, especially in unique areas, such as upper-level STEM courses. For example, students in your position have shown themselves to be highly successful. The content is just plain difficult. And, it is very unusual to see explicitly quantum behavior in the world around you-- unlike mechanics, for example. These contribute to a unique learning experience.

To make sure we're on the same page, I'd like to take a moment to briefly describe the concepts we'll be discussing. First, and most importantly, I'm looking for your perception of the class. What has your experience looked like? I would encourage you not to think about a 'right' answer, but rather about the most 'honest' answer. The goal is not to build a case for or against active learning, but to really explore and understand your experience. Second, active learning. We define active learning as an approach that uses exercises, in which students participate, during learning. For example, board activities or simulations. Third, I'll ask questions about your patterns of thinking- we sometimes refer to this as cognition, your feelings-- we sometimes refer to this as affect, and your behavior. Fourth, we sometimes use the word ‘impactful’ in these situations. In layman’s terms, this describes those times when something affects or influences you, in action, feeling, or thought. Fifth, my focus is on anything said or done as part of the class-- homework, review sessions, class time, etc. You are welcome to discuss it all. Sixth, whatever happens during the interviews is completely anonymous-- so feel free to talk about anything you want. The Instructor will have a chance to read the final paper, but all identifiers will be protected. For example, your name will be represented by a letter not identified with your name. Finally, I should remind you that your participation is completely voluntary-- if you want or need to leave at any time, you may. Do you have any questions? Great, let's get started.

Interview Questions:

1. What are up to three significant adjectives that you would use to describe your experience with active learning, at this stage?
   a. Which event best represented that experience? (for each adjective in #1)
   b. (If adjectives are different than corresponding responses in Interview 1): In the first interview, you listed j1, j2, and j3 (the three adjectives of #2),
influenced by e1, e2, and e3 (the three events of #2a). Looking back, how has your experience changed through the semester, due to active learning?

2. Which activities seemed most impactful?
   a. How was that activity impactful (for each activity in #2)?
   b. (If activities are different than corresponding responses in Interview 1): In the first interview, you listed a1, a2, and a3 (the three activities of #3). How has your response to the activities changed through the semester, due to active learning?

3. Are there any aspects of the active environment that seem detrimental or detracting to the class?
   a. If so, which ones?
   b. (If detractors are different than corresponding responses in Interview 1): In the first interview, you listed d1, d2, and d3 (the three detractors of #4). How has your perspective on detrimental aspects changed through the semester, due to active learning?

4. As a result of active learning in this class, have you adjusted your behavior (such as attendance, participation, or out-of-class work) in any noteworthy ways, as the semester has progressed?
   a. If so, can you give me an example of how you’ve adjusted?

5. In education, we sometimes talk about cognitive concepts, such as reflecting on ideas, problem-solving, focus on conceptual understanding, or just simply wanting to learn. Reflecting on these types of concepts, do you have any noteworthy reflections that you can share, that were influenced by active learning, as the semester has progressed?
   a. If so, can you give me an example?

6. Sometimes in education, we talk about feelings, like ‘frustrated,’ ‘stressed,’ or ‘intrigued.’ Can you tell me some of the feelings you’ve had, due to the active learning approach in this class, as the semester has progressed?
   a. If so, can you give me an example of when you felt this way?

7. Is there anything else you want to tell me?
APPENDIX M

FOCUS GROUP PROTOCOL
An exploration of student response to an active learning environment in an upper-level Quantum Physics course

Focus Group Protocol

Opening:
Today, we'll be exploring your experience in quantum mechanics this semester, as part of an active learning environment. As a reminder, this research is part of my thesis, which is to explore the student experience of an active learning environment in upper-level quantum mechanics. While more 'student-centered' approaches to learning are becoming more prevalent, there is still much we do not know about the student experience, especially in unique areas, such as upper-level STEM courses. For example, students in your position have shown themselves to be highly successful. The content is just plain difficult. And, it is very unusual to see explicitly quantum behavior in the world around you-- unlike mechanics, for example. These contribute to a unique learning experience.

To make sure we're on the same page, I'd like to take a moment to briefly describe the concepts we'll be discussing. First, and most importantly, I'm looking for your perception of the class. What has your experience looked like? I would encourage you not to think about a 'right' answer, but rather about the most 'honest' answer. The goal is not to build a case for or against active learning, but to really explore and understand your experience. Second, active learning. We define active learning as an approach that uses exercises, in which students participate, during learning. For example, board activities or simulations. Third, I'll ask questions about your patterns of thinking- we sometimes refer to this as cognition, your feelings-- we sometimes refer to this as affect, and your behavior. Fourth, we sometimes use the word ‘impactful’ in these situations. In layman’s terms, this describes those times when something affects or influences you, in action, feeling, or thought. Fifth, my focus is on anything said or done as part of the class-- homework, review sessions, class time, etc. You are welcome to discuss it all. Sixth, whatever happens during the interviews is completely anonymous-- so feel free to talk about anything you want. The Instructor will have a chance to read the final paper, but all identifiers will be protected. For example, your name will be represented by a letter not identified with your name. Finally, I should remind you that your participation is completely voluntary-- if you want or need to leave at any time, you may. Do you have any questions? Great, let's get started.

1. Guidelines and focus group structure discussion.

2. Topic overview, including themes from interview (X, Y, Z, A).

3. Opening question:
   a. What was the most interesting experience of the study?
Discussion Questions:

1. For each theme ‘X’, as identified by interview data analysis and relating to “How do upperclass physics majors initially engage with active learning interventions in upper-level Quantum Mechanics classes?”,
   a. Explain what is meant be ‘X’.
   b. What experiences did you have with X during the study?
   c. Where else have you experienced X in your undergraduate classes?

2. For each theme ‘Y’, as identified by interview data analysis and relating to “Which active learning exercises initially influence upperclass physics majors in upper-level Quantum Mechanics classes?”,
   a. Explain what is meant be ‘Y’.
   b. What experiences did you have with Y during the study?
   c. Where else have you experienced Y in your undergraduate classes?

3. For each theme ‘Z’, as identified by interview data analysis and relating to “How do upperclass physics majors engage with long-term active learning interventions in upper-level Quantum Mechanics classes?”,
   a. Explain what is meant be ‘Z’.
   b. What experiences did you have with Z during the study?
   c. Where else have you experienced (Z-X)^3 in your undergraduate classes?

4. For each theme ‘A’, as identified by interview data analysis and relating to “Which active learning exercises influence upperclass physics majors most, due to long-term active learning interventions in upper-level Quantum Mechanics classes?”,
   a. Explain what is meant be ‘A’.
   b. What experiences did you have with A during the study?
   c. Where else have you experienced (A-Y) in your undergraduate classes?

5. Do you have anything more to add?

---

^3 (Z-X) indicates that all thematic responses uncovered by Question 3 (Z) that were not explored by Question 1 (X) will be explored.
APPENDIX N

INTERVIEW INTRODUCTION
Today, we'll be exploring your experience in quantum mechanics this semester, as part of an active learning environment. As a reminder, this research is part of my thesis, which is to explore the student experience of an active learning environment in upper-level quantum mechanics. While more 'student-centered' approaches to learning are becoming more prevalent, there is still much we do not know about the student experience, especially in unique areas, such as upper-level STEM courses. For example, students in your position have shown themselves to be highly successful. The content is just plain difficult. And, it is very unusual to see explicitly quantum behavior in the world around you— unlike mechanics, for example. These contribute to a unique learning experience.

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APPENDIX O

OVERALL CLASS OBSERVATION RUBRIC EXAMPLE
<table>
<thead>
<tr>
<th>Sequential segments</th>
<th>W/ whom</th>
<th>What done</th>
<th>What with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different engagement type</td>
<td>Adult</td>
<td>Ask, Answer</td>
<td>Metacognition</td>
</tr>
<tr>
<td>2nd activity</td>
<td>Facilitator</td>
<td>Connect, Describe</td>
<td>Ideas</td>
</tr>
<tr>
<td>Task</td>
<td>Peer</td>
<td>Discuss, Experiment</td>
<td>Procedure</td>
</tr>
<tr>
<td>Different tasks</td>
<td>Self</td>
<td>Explain, Explore</td>
<td>Challenges</td>
</tr>
<tr>
<td>Science content changes</td>
<td></td>
<td>Identify, Listen</td>
<td>Problems</td>
</tr>
<tr>
<td>Activity structure</td>
<td></td>
<td>Observe, Predict</td>
<td>Artifacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Problem solving, Read</td>
<td>Phenomena</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use, Volunteer</td>
<td>Facts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Participate</th>
<th>Affect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active: takes initiative</td>
<td>-Aroused: Amazed, joyful, fun, happy, enthusiastic, eager, inspired, determined</td>
</tr>
<tr>
<td>Passive: listening, attentive, alert</td>
<td>-Aroused: Distressed, upset, angry, frustrated, worried</td>
</tr>
<tr>
<td>Passive: unfocused, not on task</td>
<td>-Drowsed: Drowsy, tired, Distracted, not on task</td>
</tr>
<tr>
<td>Disruptive</td>
<td>Disruptive (if and often)</td>
</tr>
</tbody>
</table>

26: M asks clarification - engaged w/ explanation

23: M is observing math, during guest.

27: M asks Q on free part, misses continuity, engaged w/ discussion

28: M mumbles answer to En guest to class

29: M writes notes

[generally watching W:R:B most of writing time]

28: M, B watch kid's asking question

B head on fist, leaning over
APPENDIX P

INDIVIDUAL OBSERVATION RUBRIC EXAMPLE
## ENGAGEMENT OBSERVATION SUMMARY

<table>
<thead>
<tr>
<th>Code</th>
<th>Cognitive</th>
<th>Behavioral</th>
<th>Affective</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>A lot to most (&gt; 50%)</td>
<td>Participation behaviors:</td>
<td>Positive Aroused: Amazed, joyful, fun, happy, enthusiastic, eager, inspired, determined, startled-positive</td>
</tr>
<tr>
<td>3</td>
<td>Some (25-50%)</td>
<td>Active. Active, takes initiative, eager to participate. (e.g., hand raising, asking and answering questions are ok to code as Active in a setting without physical opportunity.)</td>
<td>Positive UA: Alert, calm, relaxed, at ease</td>
</tr>
<tr>
<td>2</td>
<td>Rarely (&lt; 25%)</td>
<td>Passive +. Ready to learn and participates.</td>
<td>Negative UA-Bored</td>
</tr>
<tr>
<td>1</td>
<td>Not observed (0%)</td>
<td>Passive -. Doesn't take initiative, gives up, unprepared, or distracted.</td>
<td>Negative UA-Sad/Drowsy/Tired</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disruptive. Actions interfere with self and other's learning.</td>
<td>Negative Aroused: Distressed, upset, angry, frustrated, worried, startled-negative</td>
</tr>
</tbody>
</table>

- **Metacognition:** Thinking about learning process. Self-regulation; Choosing which strategy or approach to use.
- **Challenges, problems**: Working to goal without prescribed procedure; iterating, trial & error, etc.
- **Ideas:** Discussing causality, mechanism or fundamental principles; explaining, connecting, relating
- **Skills**: Dealing with physical properties; describing, observing, sketching; using simple devices
- **Phenomena**: Exploring action/behavior (beyond physical properties) under different circumstances
- **Procedures**: Following prescribed instructions to complete a task. Step-by-step directions.
- **Facts**: Writing, reading, labeling, memorizing or reviewing factual materials such as names, dates, masses, weights, etc. Dealing with bits of canonical knowledge.

### Engagement with:

- **Social Interactions:**
  - with Peer
  - with Adult
  - with Facilitator

### Overall Engagement: (circle 1 per row)

<table>
<thead>
<tr>
<th>Affective</th>
<th>Behavioral</th>
<th>Cognitive</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive Aroused</td>
<td>Very High</td>
<td>Very High</td>
<td>Very High</td>
</tr>
<tr>
<td>Positive Unaroused</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Flat</td>
<td>Medium</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Mixed</td>
<td>High</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Negative Unaroused</td>
<td>Medium</td>
<td>Low</td>
<td>Very Low</td>
</tr>
<tr>
<td>Negative Aroused</td>
<td>Low</td>
<td>Very Low</td>
<td>Very Low</td>
</tr>
</tbody>
</table>
APPENDIX Q

ANALYSIS THEME CONCEPT MAP
Research Question 1

- Vibrancy
- Time Pressure

Research Question 2

- Individual Work
- Group Activities
- Public Work

Change in Perception

- More Natural

Case Insights

- Students Differ
- Implementation Difficulties
- Community Matters
- Hard but Rewarding
<table>
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<tr>
<th>#</th>
<th>THEME</th>
<th>DESCRIPTION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Time Pressure</td>
<td>Increased pressure or stress regarding getting everything done in class.</td>
<td>“Homeworks feel a little rushed”</td>
</tr>
<tr>
<td>2</td>
<td>Vibrancy</td>
<td>Increased intensity of experience, such as curiosity, motivation, and problem-solving.</td>
<td>“There is an energy in the class…”</td>
</tr>
<tr>
<td>3</td>
<td>Group Activities</td>
<td>Working in groups, at the board or at a desk.</td>
<td>“I enjoy doing group activities…”</td>
</tr>
<tr>
<td>4</td>
<td>Public Work</td>
<td>Working through problems in a public setting.</td>
<td>“[Working in public helped to] clarify weak points.”</td>
</tr>
<tr>
<td>5</td>
<td>Individual Work</td>
<td>Working through problems individually or in a smaller group (3-4 students)</td>
<td>Most of the times when we were at the board [were stressful] because I feel like I perform a lot better when I’m working as an individual.</td>
</tr>
<tr>
<td>6</td>
<td>More Natural Over Time</td>
<td>Becoming more accustomed to active learning exercises as the semester continued.</td>
<td>“[I am] warming to [public work].”</td>
</tr>
<tr>
<td>7</td>
<td>Students Differ</td>
<td>While many trends surfaced, students seldom were of a common voice on all trends.</td>
<td>“I enjoy doing… simulations.” “[Simulations are] weak.”</td>
</tr>
<tr>
<td>8</td>
<td>Community Matters</td>
<td>Knowing one’s peers and colleagues was a strong influence.</td>
<td>“[Class was more accessible because peers were] struggling right there beside them.”</td>
</tr>
<tr>
<td>9</td>
<td>Hard but Rewarding</td>
<td>Engaging with the course was more difficult, but the added energy felt worthwhile.</td>
<td>“Labor intensive… but rewarding.”</td>
</tr>
<tr>
<td>10</td>
<td>Implementation Difficulties</td>
<td>Difficulties in operationalizing active learning strongly influenced student perception and response.</td>
<td>“I feel like we are barely covering material and I’m not learning during class.”</td>
</tr>
</tbody>
</table>