ANALYSIS OF SELF-DIRECTED MASTERY LEARNING OF HONORS PHYSICS

By

WENDY ATHENS

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To Alexis, Andrew, and Katie, who have sacrificed to earn this degree with me

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LIST OF ABBREVIATIONS

FCI	Force Concept Inventory (FCI) is a validated assessment tool that measures conceptual understanding of physics without requiring formal education in physics. This tool was developed by Halloun and Hestenes (1985) and its widespread adoption has enabled secondary and university physics instructors to gauge the impact of pedagogical changes on students' conceptual understanding.
LFM	Learning for Mastery (LFM) is an instructional practice attributed to Benjamin Bloom (1968) that is based on the foundational belief that every student can attain concept mastery given enough time and adjustment of instructional methods.
MOPS	Minds on Physics (MOPS) is a curriculum developed by the Physics Education Group at the University of Massachusetts (http://www.physicsclassroom.com/mop/). MOPS is built on constructivist principles and is interactive and increases in complexity, requiring effort on the learner's part.
PBB Lab	The Pendulum Box Bash Lab was adopted from Zou (2000) of Ohio State University, and demonstrated conditions under which conservation of energy laws DO NOT apply and conservation of momentum laws DO apply. The central idea of the lab was to account for energy losses in inelastic collisions.
PhET	Physical Educational Technology – PhET – from University of Colorado at Boulder - provides fun, interactive, research-based simulations of physical phenomena (http://phet.colorado.edu). PhET enables students to make connections between real-life phenomena and the underlying science, deepening their understanding and appreciation of the physical world.
PIVOT	Physics Interactive Video Tutor (PIVOT) was developed and implemented at MIT (Lipson, 2001 and encompassed video lectures are interspersed with interactive questions to create a virtual mentoring environment.
PSI	Personalized System of Instruction (PSI) is a form of mastery learning attributed to Fred Keller (1968). PSI involves self-paced, largely text-based learning with retesting on identical tests until mastery is reached.
RQ	Research Question
TEAL	Technology-Enabled Active Learning (TEAL) has evolved over 10 years as a joint research partnership between the MIT Teaching and Learning Laboratory and the MIT Physics Department. The TEAL project has transformed freshman physics from a

lecture/recitation format to a studio physics model that combines short presentations with in-class desktop experiments and conceptual problem-solving teams (Breslow, 2004).

VOLO — A VOLO, an acronym for Vocabulary – Objectives – Learning Options, is a learning contract. Typically, the VOLO appears as a 9-squared tic-tac-toe box on the student's web page, and the student contracts with the instructor for which five activities he or she will complete for the learning unit. A student must earn a score of 80% to receive a completion mark for the VOLO task. The grading scale for VOLOs is typically: 5 of the 9 tasks completed = 100%, 4 tasks = 85%, 3 tasks = 60%, 2 tasks = 30%, 1 task = 0%.

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ANALYSIS OF SELF-DIRECTED MASTERY LEARNING OF HONORS PHYSICS

By

Wendy Athens

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Self-directed learning (SDL) is an important life skill in a knowledge-based society and prepares students to persist, manage their time and resources, use logic to construct their knowledge, argue their views, and collaborate. The purpose of this study was to facilitate mastery of physics concepts through self-directedness in formative testing with feedback, a choice of learning activities, and multiple forms of support. This study was conducted within two sections of honors physics at a private high school (N=24). Students' learning activity choices, time investments, and perceptions (assessed through a post survey) were tracked and analyzed. SDL readiness was linked to success in mastering physics concepts.

The three research questions pursued in this study were: What SDL activities did honors physics students choose in their self-directed mastery learning environment? How many students achieved concept mastery and how did they spend their time? Did successful and unsuccessful students perceive the self-directed mastery learning environment differently?

Only seven of 24 students were successful in passing the similar concept-based unit tests within four tries, and these seven students were separated into a "successful"

group and the other 17 into an “unsuccessful” group. Differences between the two groups were analyzed. A profile of a self-directed secondary honors physics student emerged. A successful self-directed student invested more time learning from activities rather than simply completing them, focused on learning concepts more than rote operations, intentionally selected activities to fill in gaps of knowledge and practice concepts, actively constructed knowledge into a cognitive framework, engaged in academic discourse with instructor and peers as they made repeated attempts to master content and pass the test given constructive feedback, used a wide variety of learning resources, and managed their workload to meet deadlines.

This capstone study found that parallel instruction in content and SDL skills could be important for improving learning outcomes and better equipping secondary honors physics students for college and life in general. Mastery learning principles coupled with modeling in self-direction appear mutually reinforcing and, when more explicitly approached, should yield dual benefits in concept mastery as well as self-efficacy.

CHAPTER 1
INTRODUCTION

Although science education is considered critical to national security and economic vitality, much evidence points to unremarkable performance of American students in science (Gates, 2007; Hart & Rudman, 2001). "Our success as a nation depends on strengthening America's role as the world's engine of discovery and innovation" (Whitehouse Press, 2010). The United States received an "average" rating for science in the 2009 Program of International Assessment (PISA, 2009). The 2005 National Assessment of Educational Progress (NAEP) science section showed 46% of American 12th graders do not meet the "basic" threshold for science, 18% are "proficient," and only 2% are "advanced" (NAEP, 2005). The National Science Foundation ranked the United States 73 out of 91 countries surveyed in the fraction of its college students obtaining bachelor's degrees in science and engineering (NSF, 2006). Only 17% of American students chose such careers, compared to 52% of Chinese, 41% of Korean, and 38% of Taiwanese college graduates (NSF, 2006). In 2003, China graduated 5.8 times as many engineering students as the U.S. (NSF, 2006). American universities bemoan the preparation of incoming freshmen in science and other subjects (Report of the Academic Competitiveness Council, 2007).

To foster learning of physics in particular, this capstone project revived a tried-and-proven instructional strategy – mastery learning (Bloom, 1968; Guskey, 2010) – in a self-directed and technology-enabled secondary honors physics course. Self-directed learning (SDL) was incorporated because it is recommended as an important life skill and can contribute to more meaningful learning as learners follow their interests, learning styles, and skill sets (Abdullah, 2001; Partnership for 21st-century skills, 2009).

The focus of the project was to determine the types of learning activities and support structures learners preferred in their self-directed learning of a secondary physics unit on conservation of energy and analyze how learning activities and support structures impacted concept mastery. The corresponding research questions (RQ's) are listed and then detailed below:

RQ #1: What SDL activities did honors physics students choose in their self-directed mastery learning environment?

RQ #2: How many students achieved concept mastery when SDL activities were infused into the honors physics classroom for a given time period, and how did they spend their time?

RQ #3: Did successful and unsuccessful students perceive the self-directed mastery learning environment differently?

RQ1: What SDL activities did honors physics students choose in their self-directed mastery learning environment? The SDL aspect was designed and integrated in the form of learning contracts called VOLOs (Vocabulary – Objectives – Learning Options) which provided freedom to choose among a limited number of learning pathways. Learning contracts provide a way to develop individualized skills and knowledge while respecting differences in learning styles, readiness, and interests (Guglielmino, 2000). The three types of support investigated were one-to-one tutoring with the instructor (also called *expert tutor*), peer instruction, and computer tutorial support. The focus on tutor support – whether from an expert, a peer, or a computer – was an outgrowth of mastery learning emphasis on tutors (Bloom, 1968). Bloom felt that the ultimate learning environment was one-to-one expert tutoring, and in such an environment he believed every student could reach concept mastery given sufficient time, feedback, and support (Bloom, 1968). More recent work in mastery learning gives evidence that computer tutor support improved learning outcomes as effectively as an expert tutor (Morote &

Pritchard, 2009; Ogilivie, 2001). To address this question, data collection included VOLO choices and also daily Time Tickets (Appendix A) that tracked how the student allocated their time among the *SDL activities*, meaning learning activities and three support types.

RQ2: How many students achieved concept mastery when SDL activities were infused into the honors physics classroom for a given time period, and how did they spend their time? The most important form of feedback in mastery learning is formative testing that serves as a guiding beacon for the efforts of learners and tutors (Bloom, 1984). At the end of the four-week learning unit, the students who had passed the unit test with at least an 80% given four tries were separated into the "successful" group. Choices and time investment in SDL activities of successful versus unsuccessful students were compared.

RQ3: Did successful and unsuccessful students perceive the self-directed mastery learning environment differently? A post survey (Appendix B) probed student perceptions of SDL, attitudes and approaches to learning physics, and views on the capstone's self-directed mastery learning environment. The survey instrument was developed from three validated instruments – Guglielmino's (1977) Self-Directed Learning Readiness Scale (SDLRS), Halloun's (2001) Views About Sciences Survey (VASS), and the Colorado Learning Attitudes About Science Survey (CLASS, 2006) – as well as custom questions about the capstone's course design. Responses were compared between successful and unsuccessful groups to determine differences in SDL readiness, problem-solving strategies and development of expert thinking about physics, and preferences in learning environment. Statistical significance of the comparison was determined using the Mann-Whitney U Test due to the small sample size (N=24) and non-normal distribution of responses.

To summarize, this capstone project sought to improve learning outcomes in a secondary physics course by incorporating self-directed mastery learning elements in a technology-rich environment. This was a year-long effort, and the capstone focused on one four-week unit, the conservation of energy unit. The SDL activities of students that were/were not successful in mastering concepts were compared. The determinant of concept mastery was passing the unit test with an 80% within four tries, given constructive feedback and correctives. A post survey was administered to determine perceptions of SDL, attitudes and approaches to learning physics, and opinions about the capstone's self-directed mastery learning environment. To develop a profile of a self-directed secondary honors physics student, SDL activity choices, time allocations, and survey responses between successful and unsuccessful students were compared.

CHAPTER 2
LITERATURE REVIEW

Figure 2-1 presents an image of the capstone niche that merges four conceptual domains and preludes this literature review. These four conceptual domains are Physics Education Research (PER), Learning for Mastery (LFM), Self-Directed Learning, and Technology. PER is a well-developed branch of science education driven by the availability of pedagogical assessment tools that provide essential feedback on instructional innovation (Hake, 2007). The review of rich PER literature highly influenced this work to blend traditional instruction with peer interaction, hands-on inquiry, and technologies such as animations.

Figure 2-1 illustrates the influence of LFM and SDL on the capstone design. The LFM aspect was incorporated in many forms of feedback and support, a flexible timeline, and multiple tries to reach at least an 80% on the unit test. Students were encouraged to work one-to-one with the instructor to review tests and glean feedback to overcome their misconceptions. As mentioned, SDL was fostered by the use of VOLOs, plus the allocation of approximately 75% of class time to independent work.

Technology was integral to the capstone design both from infrastructure and educational technology perspectives. The literature review of technology encompasses Web 2.0, Google® Apps, computer tutors, animations and simulations, and blended learning. A Google® Apps infrastructure was essential to smooth operation of the capstone's learning environment. Through Google® Apps, students were editors of the class website (a Web 2.0 feature), which enabled them to manage their personal web pages containing their VOLOs and electronic file cabinets. Google® Apps also provided a content management system and enabled easy communication between instructor-student and student-student. Google® Forms was used to capture daily Time Ticket data. Computer tutors were incorporated because they served as a primary means of self-directed learning and provided another feedback source for students. Animations and simulations were used to focus the learner's attention on the science phenomenon of interest and allow manipulation of variables for cause-effect analysis (Wieman, 2008). Finally, this capstone's learning environment can be classified as a blended learning environment because it employed approximately 25% face-to-face (FTF) and 75% SDL, which was primarily online work. The literature review thus considers the emerging understanding of blended learning models and considers literature recommendations in the creation of FTF and SDL activities.

Physics Education Research

Over three decades of substantive and extensive research correlating pre-/post-validated test scores with various instructional strategies in mostly college physics courses provided great support for this capstone. Physics education reform has outpaced other scientific disciplines largely because Halloun and Hestenes (1985) developed the Force Concept Inventory (FCI) assessment tool, which was designed to determine conceptual understanding without formal training in mechanics (Hestenes, 1995). The widespread adoption of the FCI as a comparative tool has allowed physics instructors everywhere to assess their classroom performance relative to an average and receive feedback on their adaptations in pedagogy (Hake, 2007).

A bedrock PER belief is that "incorrect science concepts [are] tenacious and resistant to extinction," according to University of North Carolina's Joel Mintzes (2007, p. 366). Carrying these misconceptions forward results in rote equation-grabbing approaches rather than in reflective problem solving. It is difficult to foster conceptual change through traditional instruction, and one important role of the tutor, whether human or computer, is to highlight the discrepancy and create conceptual conflict (Ozmen, 2008).

Table 2-1 summarizes noteworthy PER contributions that relate to this capstone project, including computer tutorials, modeling, interactive engagement, active learning, and online lectures. The highlights include the role of interactive engagement and breaking away from traditional lecture (deemed largely ineffective by Crouch, 2001; Hake, 1998; Mazur, 1997; Meltzer, 2002; Reddish, 1999). As a result of such research some major universities have transformed large lecture halls into engaging, small-group problem solving sessions through interactive quiz and response systems (Crouch, 2001; Mazur, 1997). Given the small class sizes in this capstone and the predominance of small-group work, interactive engagement is integrated into the capstone. Another highlight is the role of active learning and hands-on experiments. Elaborate designs have emerged over the years at MIT, University of Washington, North Carolina State University, and other universities (Beichner, 2000; Breslow, 2007; McDermott, 2002). While the capstone does not employ such elaborate learning spaces, it does incorporate animations, collaborative learning, hands-on experiments, and a commitment to SDL.

Mastery Learning

Mastery learning, defined as a feedback-corrective response instructional strategy based on formative testing, gained prominence over four decades, peaking in the 1970s. Few strategies have been implemented more broadly or evaluated more thoroughly (Guskey, 2010). For instance, Whiting (1995) compiled 18 years of data gathered from more than 7000 high school students and showed mastery learning yielded not only higher test scores and GPAs but also better attitudes towards school (Guskey, 2007). Exam scores, retention rates, and student attitude evaluations were superior in mastery learning to those in traditional classrooms, with learning gains measuring up to the 1 sigma range (Guskey, 2007). On a typical bell curve distribution, a 1 sigma learning gain corresponds to the midpoint moving from 50% to 84%.

Bloom believed time, not aptitude, is the determinant of performance (Bloom, 1968). Aptitude tests simply indicate how much time will be required for the student to reach mastery. “Mastery learning theorists suggest that rather than holding instructional time constant and allowing achievement to vary (as in traditional instruction), achievement level should be held constant and time allowed to vary” (Slavin, 1987A, p. 197). Figure 2-2 illustrates the formative testing and feedback loops of LFM as well as the branching that occurs as advanced students enter enrichment activities while lagging students lay firmer foundational knowledge. Interestingly, LFM research indicates classrooms that start off staggered due to readiness differences, but emphasize correctives, yield powerful benefits as lagging students catch up (Guskey, 2007).

Bloom (1968) promoted the personal expert tutor as the ideal learning environment. An expert tutor enabled the average student to outperform 98% of non-tutored students, a 2-sigma improvement, yet was expensive to execute (Bloom, 1984). Bloom sought which critical elements in one-to-one tutoring could be transferred to whole-class settings. Bloom focused on assessments being prescriptive and on implementing feedback-corrective cycles (Bloom, 1984). In later work (Table 2-2), Bloom sought additive effects by combining mastery techniques with other reasonable adjustments a classroom educator could make, such as reviewing prior material one week before starting new material (a 1.2-sigma gain), increased classroom participation (1-sigma), cooperative learning (0.8-sigma), graded homework (0.8-sigma), study skill instruction (1-sigma), and improved time on task (1-sigma) (Bloom, 1984). Several of these interventions are incorporated into the capstone design including one-to-one tutor, computer tutor, review, improved time on task, mastery learning, classroom participation, cooperative learning, and graded homework.

Bloom believed the bell curve was the greatest disservice of the American educational system and that 90% of students could master material if the educator adapted methods and materials and gave them enough time, just as a personal tutor would do (Bloom, 1968). An unexpected outcome of mastery learning was the cooperative learning environment it fostered through its peer support system, which was enhanced by the fact that high grades were no longer a scarce commodity and that all could earn an A (Bloom, 1978). Another interesting outcome was the similarity of learning rates that occurred over time in the mastery learning groups versus the control groups. All classrooms began with an estimated 5:1 ratio in rate of learning, meaning top students finished material five times faster than slower students, which practically disappeared in the mastery classroom but became more pronounced in control classrooms (Bloom, 1978). Bloom attributed this to increased self-confidence resulting from academic success and the fact that constant feedback enabled students to develop self-efficacy sooner (Bloom, 1978).

Fred Keller of Arizona State University was a contemporary of Bloom's. He designed the Personalized System of Instruction (PSI) and saw excellent results (Keller, 1968). Because PSI involved feedback with correctives (from peer, not expert tutors) and frequent assessments, it was also a form of mastery learning, and in fact during the mastery learning heyday, two-thirds of all published mastery learning case studies were PSI initiatives (Kulik, Kulik & Bangert-Drowns, 1990). Modern PSI involves computer tutors that support multiple attempts to master the same test (Cracolice & Roth, 1996; Eyre, 2007). In contrast, Bloom's approach, based on whole-class instruction followed by the expert tutor crafting an individual corrective (or enrichment) pathway for each learner, was called Learning for Mastery, or LFM, and is more closely associated in modern terms with differentiated instruction, Response to Intervention, and Understanding by Design (Guskey, 2010). Commonalities across these instructional strategies include bedrock high-quality group instruction, regular formative assessments, individualized corrective instruction, and enrichment activities for advanced learners while slower learners catch up (Guskey, 2010; Tomlinson & McTighe, 2006).

For all of the successes of mastery learning, today the term rarely appears in the literature, common only in pharmacy and law schools (Eyre, 2007; Lockman, 2008). There may be many reasons for this including the re-packaging just mentioned. Eyre (2007) attributes inertia and cost efficiencies of the lecture system, which discourage any change from traditional instruction. Another key factor cited is the daunting workload of the first year of mastery implementation, including the generation of worksheets to accompany texts, multiple forms of quizzes and tests, increased tutoring hours, and classroom management complexities of asynchronous work (Eyre, 2007). Guskey (2007) states that students are more actively engaged in mastery learning classrooms and that a firmer foundation is laid early such that more rapid progress is possible than for the majority of students in traditional classrooms.

Self-Directed Learning

Self-direction is recommended as an important life skill to be fostered by K-12 science education (Partnership for 21st-century skills, 2009). A self-directed learner has a desire to learn and the motivation to persist in the learning process (Guglielmino 1989; Taylor, 1995). Self-discipline is coupled with basic study skills and time-management skills to support the learner's motivation (Taylor, 1995). Granting the self-directed learner greater autonomy can contribute to more meaningful learning as the learner chooses learning strategies that interest them and complement their skill set (Abdullah, 2001). Some studies indicate greater retention for active and self-directed learning (Dori, 2007).

The first SDL literature appeared in 1967 when Alan Tough discussed "self-teaching" as adults decided what, when, and how to learn (Tough, 1967, p.3). Knowles (1975) extended these ideas with rationale, stating SDL was beneficial because proactive learners retained more than reactive learners, which was a mark of maturity, and this cultivated the initiative essential to educational success. The goals of SDL are realized when learners think for themselves in a systematic way and construct their own perspective (Candy, 1991). SDL helps students learn how to learn and challenges them to challenge themselves (Gibbons, 2002). Relating SDL to science education, engaging learners in scientific inquiry helps them experience the scientific process (not just facts) with its strengths and limitations (van Joolingen, 2007). Inquiry learning is a favored instructional strategy because it simulates real-world challenges and develops necessary life skills such as finding creative alternatives, persisting, using logic, and negotiating one's view (van Joolingen, 2007). Research shows that scientific researchers experience research as a complex, cyclic and iterative process that often involves argumentation to produce scientific knowledge (van Rens, 2010).

One of the most important tasks of the SDL instructor is raising student awareness of their responsibility to manage their own learning (Idros, 2010; Taylor, 1995). Other contrasts between SDL and traditional, teacher-directed learning are highlighted in Table 2-3 (Gibbons, 2002). Table 2-3 shows a gradual release of control from the instructor to the student between teacher-directed and student-directed learning. In SDL, the student increasingly manages setting personal learning goals, processes, and even assessments (Abdullah, 2001; Gibbons, 2002). As learners assume greater responsibility to diagnose their learning needs, strategize on how to acquire the necessary knowledge, and set personal learning goals including timelines, they are developing critical career survival skills (Guglielmino, 2000). Bolhuis (2003) describes how a teacher must strike a balance between content-oriented and process-oriented instruction (process-oriented instruction relates to SDL skill development). The balance involves providing content instruction in a positive emotional climate within a social context in parallel with pushing students a little outside their comfort zone for self-direction (Bolhuis, 2003). The capstone's learning unit provided an SDL environment but did not incorporate explicit instruction in SDL strategies; however, future iterations should, as will be discussed in Chapter 5, Future Work.

Interestingly, although SDL is inherently individualistic, it requires increased collaboration between the student, the teacher and peers (Abdullah, 2001; Hogg, 2008). SDL has roots in social constructivist theory (Gibbons, 2002; Idros, 2010). Instructors support SDL through constructive discourse (Herbal-Eisenman & Breyfogle, 2005) and by modeling problem-solving methods and Learning to Learn strategies (Pape, 2000). Teachers can create environments in which students do not fear making a mistake, and collaboration is frequent so socio-cognitive construction of knowledge is possible (Buschman, 2003). By incorporating more real-world aspects into the learning environment, the instructor can lend significance and meaning to the learning process (Bransford, 2000).

Another important environmental factor that the instructor can use to support SDL is offering a choice of learning activities. Learning contracts allow learners to choose their pathway to acquire needed skills and knowledge while respecting individual differences in learning styles, readiness, and interests. The pertinent questions that the learner should ask (initially under the guidance of the instructor) when developing a learning contract include (Guglielmino, 2000): What do I need to be able to do? What resources will I use to learn this? What is the targeted completion date? How will I measure that I have attained the goal? The VOLO structure of the capstone and multiple forms of support provided capstone students with choice.

A validated SDL assessment tool developed in 1997 by Guglielmino is called the “Self-Directed Learning Readiness Scale” (SDLRS). Over 150 studies have employed the SDLRS, mostly in adult settings (Chou, 2008). The SDLRS uses a 58-item Likert-scale analysis along with eight factors to assess readiness (Guglielmino, 1989): openness to learning opportunities, self-perception as an effective learner, driving initiative as an effective learner, acceptance of responsibility for one’s own learning, love of learning, creative spirit, future orientation, and ability to use basic study and problem solving skills. The SDLRS is thought to be most appropriate for adult audiences with a higher educational status (Chou, 2008; Hendry, 2009). Questions from the SDLRS were selected and incorporated into the capstone's post survey.

Technology

Jonassen (2003) identifies several ways technology can be thoughtfully integrated into the instructional design, which is ideally anchored in a real-world problem. These technology tools include multimedia presentation of ideas, information access, simulations and animations to represent difficult concepts, collaboration and communication tools. The technology literature review focuses on four aspects relevant to the capstone's self-directed mastery learning environment: animations and simulations, blended learning, computer tutors, and Google® Apps/Web 2.0. Animations and simulations were embedded in the VOLOs and functioned as learning tools. Blended learning is reviewed because the capstone learning environment was fundamentally a blended learning environment with 25% whole-class face-to-face instruction and 75% SDL. Computer tutors functioned as the third major support for students in combination with expert and peer support. Finally, Google® Apps/Web 2.0 is reviewed because the technology infrastructure for the capstone learning environment was based on a Google® Apps for Education platform.

Animations and Simulations in Science

Research-based computer animations, such as PhET (Physical Educational Technology), allow the learner to interact with parameters and help to create conceptual conflict (Ozmen, 2008; Wieman, 2008). Bransford (2000) states that identifying a misconception is the beginning of learning, and animations are powerful tools to surprise the user with an unexpected outcome. Learners must make a conscious effort to recompose their thinking as they manipulate parameters and engage in cause-effect analysis (Wieman, 2008). Wieman (2008) perceives animations as more focused and filtered than real-world demonstrations, which eases the learner's cognitive load. PhET's multiple representations are reinforcing (Wieman, 2008) and appeal to different intelligences (Bransford, 2000). The value of PhET is enhanced by the collaborative contribution of the PER community in providing supporting worksheets to guide explorations of the animations.

Minds on Physics (MOPS; http://www.physicsclassroom.com/mop/) is a tutorial system developed by the Physics Education Group at the University of Massachusetts. MOPS is built on constructivist principles and is interactive and increases in complexity, requiring effort on the learner's part. The learner climbs ten (usually) levels per learning unit and gains a sense of achievement as well as understanding in the climb. Each learning unit is focused on real-world scenarios and asks conceptual and quantitative questions. If a user misses more than two questions, he or she drops down to the beginning and must restart the climb (Gerace, 1999).

Blake & Scanlon (2007) consider features for effective use of simulations in distance science education. Specifically, effective simulations use multiple representations, such as graphs and images, and are based on real data. Help is integrated and tiered according to the ability level of the user. This latter recommendation concurs with cognitive load considerations described by Clark (2005) and van Merrienboer (2003).

Blended Learning

> Educationally useful research on blended learning needs to focus on the relationships between the different modes of learning (for example, face-to-face and online) and especially on the nature of their integration. In

> particular, such research needs to generate usable evidence about the quality of the students' learning experiences and learning outcomes. In turn, this demands appropriately powerful methodologies, rooted in a firm theoretical foundation. (Bliuc, 2007)

This capstone project seeks to address Bliuc's recommendation above to optimize the design of the blend with respect to learning outcomes based on a firm conceptual foundation. The capstone's self-directed and supported mastery learning environment is a blended learning environment, with intentional integration between FTF and online components.

The U.S. Department of Education's (2009) meta-analysis of 51 studies comparing online, FTF, and blended learning found classes with online learning (either completely online or blended) outperformed classes based solely on FTF instruction. The mean effect size for all 51 contrasts was +0.24, $p<0.001$. If only blended courses were compared to FTF courses, the effect size was even more significant, +0.35, $p<0.0001$. Blends of online and FTF instruction, on average, had stronger learning outcomes than did FTF instruction alone (US DOE, 2009).

Koohang (2009) has developed a learner-centered model for higher education and considers the instructional design of the blend. Under FTF activities, he groups lectures, individual/group discussions, labs, presentations, and assessments. Under online activities he groups individual learning activities, collaborative learning activities, and assessments. He details the form and function of each of these activities and explains how each contributes to the elements of constructivism. Online learning provides an ideal space for self-paced, constructivist learning (Koohang, 2009).

Combining the work of Koohang and Bliuc with the latest US DOE report (2009), *Handbook of Blended Learning* (2006), and Bates' book (2003), it is apparent that tremendous opportunity exists for research and development in the blended learning arena. As Bates (2003) states, it is relatively easy to find the technology skill set, but to couple this with instructional design talent is a rare find. It was hoped that the capstone project could link learning outcomes with blended learning design, in particular relating VOLO activities and support choices with conceptual development.

Rapid growth in blended learning challenges instructors and students to view education differently. Bates and Poole (2003) state the design of blended courses challenges instructors to reevaluate the use of class time. Students must assume more responsibility for their learning, and instructors must evolve their role to becoming a facilitator of learning rather than a transmitter of knowledge. At the University of Central Florida, 87% of instructors indicated that they have changed their approach to teaching as a result of their online teaching experience (Bonk, 2006). They became more responsive to student needs, changed their course development and delivery methods, incorporated more technology into teaching, and used more resources (Bonk, 2006). This viewpoint is pertinent to the mastery learning environment, in which instructors serve as expert tutors and instructional designers, providing feedback and correctives to individualize instruction.

In her open access document "Lessons learned: Findings from MIT initiatives in educational technology (2000-2005)," Teaching and Learning Lab Director Lori Breslow discusses the shift of responsibility to the learner in an active learning classroom:

> The shift from passive recipient of information to active user requires a major re-conceptualization of who is responsible for what, under what circumstances, and to what end. This kind of substantial redefinition of roles takes both time and effort. The ability of educational technology to deliver more information, in more forms, anytime and anywhere is going to

> be one of the prime movers in redefining that relationship whether students and their teachers are ready for it or not. (Breslow, 2007, p. 293)

Technology learning curves are an additional factor to consider when transitioning to an active and self-directed learning environment. Instructors must offer more structure and guidance, especially in the beginning.

Skill & Young (2002) present a hybrid model that captures the best of the physical and virtual worlds. Powerful FTF teaching is coupled with online content richness and interactivity. Online work empowers the individual and emphasizes time on task activities such as virtual teamwork and interactive simulations. Applying Skill & Young's ideas to this capstone project, an optimal blend was sought between FTF/online interactions (student with expert/peer/computer), whole-class, and self-paced VOLO activities. Time allocation was tracked for a better sense of individual time investment in SDL activities.

Computer Tutors

> Some scholars assert that simulations and computer-based models are the most powerful resources for the advancement and application of mathematics and science since the origins of mathematical modeling during the Renaissance. (Bransford, 2000, p.215)

Computer tutors offer several advantages over human tutors. Besides 24x7 access, computer tutors provide immediate feedback, a huge advantage in the learning process (Chickering & Gamson, 1991). Feedback is essential, in fact, "meaningful feedback is likely the most powerful tool that can be used to improve performance" (Anglin, 2008). Although the feedback is only as valuable as the background programming, increasingly more sophisticated programming will one day allow computer tutors to better reflect expert reasoning and pedagogy, becoming a virtual extension of the expert tutor. Computer tutors are "amazingly patient" (Littlejohn, 2002) and can increase time on task. Time on task is closely related to learning (Cavanaugh, 2009; Morote, n.d.). Computer tutors are comparatively inexpensive. For instance, the annual registration for masteringphysics® was $20 for the capstone's physics students. Computer tutors offer animations and simulations that a human cannot equal. The computer allows scaling down of inquiry tasks to reduce cognitive load (van Joolingen, 2007). Wong (2001) found frequent computerized formative assessments stimulated students to work harder. Keller's Personalized System of Instruction (1968) had a self-paced structure that adapts well to computer tutorial environments (Cracolice, 1996; Eyre, 2007; Gagne, 1998).

Some disadvantages of computer tutors include the following: feedback is never original (granted, artificial intelligence is advancing); IT skills and cognitive load considerations are important, but difficult to program (Breslow, 2007; Littlejohn, 2002; Park, 2009); and computer tutors can only simulate the warmth and connection of another human.

As far as design of computer tutors, Mayer's multimedia strategies (2005) speak of the need for an uncluttered learning space with graphics and text or graphics and narration in proximity. Navigation bars are doubly effective in clearly setting expectations and organizing content (Chickering & Gamson, 1991) and preventing less technically savvy students from getting lost in descending web pages (Clark ,2005; van Merrienboer, 2003). Van Joolingen (2007) and Chang (2008) investigated different aspects of computer support of self-directed inquiry learning in science. Van Joolingen (2007) sought to optimize the balance between preserving inquiry as the process of learning science with the conflicting need to provide learners with some framework.

When supported computer environments failed to yield cognitive gains, van Joolingen (2007) attributed this to either insufficient time for knowledge building or a mismatch of support structure to the knowledge-building process.

Interaction is a desirable feature for tutorial systems because understanding is more likely to come if learners are actively engaged (Littlejohn, 2002). The term "interactive" requires some clarification and should involve students manipulating parameters to be truly effective (Littlejohn, 2002; Wieman, 2007). Park's (2009) work with presenting physics concepts to 5^{th}-grade students showed that students with limited prior knowledge had difficulty with highly interactive simulations, but high prior knowledge students did not. Park (2009) recommends adaptive simulations that stage according to cognitive load. "Novices without guidance quickly become disoriented" (Morote, n.d., p 14).

MIT's Pritchard created masteringphysics® based on mastery learning principles (hence the name) (Morote & Pritchard, 2009). He wanted to capture the large amounts of time students invested doing homework and use that time to build accurate conceptual models. Pritchard states that only 60% of students answer a physics problem right the first time, but with the masteringphysics® tutorial system, 94% of students achieve mastery (Pritchard, 2010). The computer tutorial system incorporates scaffolding and Socratic questions, and on average 15% learning gains are realized with each successive hint. Pritchard's work demonstrates 2-sigma improvement in final exam performance for those students who choose to use masteringphysics® over those who do not, which equals learning gains associated with a personal tutor (Morote &

Pritchard, 2009). Masteringphysics® served as the primary computer tutor in the capstone study.

In one study Ogilvie (2001) integrated masteringphysics® tutorial system, written homework, small group tutoring, collaborative complex problem solving, and instructional videos and correlated their usage with FCI performance gains. Masteringphysics® generated double the FCI performance gains of written homework. Collaborative complex problem solving contributed to more modest learning gains, and the latter two were unremarkable in their effects. Ogilvie (2001) concluded that masteringphysics® was more than twice as effective as written homework in improving students' conceptual understanding.

An interesting study at Carnegie Mellon's Human-Computer Interaction Institute shows that the ACT Programming Tutor generated 1.76-sigma gains over traditional instruction. The ACT tutor incorporated three aspects: modeling (0.75-sigma), individualized feedback (0.89-sigma), and scaffolding (0.42-sigma). Arguably, this is on par with an expert human tutor (Corbett, 2001). Another commercial system is ALEKS®, which adjusts questions according to student readiness and periodically checks for retention (Eyre, 2007).

Google® Apps/Web 2.0

Google® Apps is a cloud computing environment hosted on Google® server farms using Python programming language and Bigtable distributed storage systems, and in these early stages is offered free to schools and universities (Hayes, 2008). As a cloud application, Google® Apps provides schools and universities with virtually unlimited remote server capacity with outsourced maintenance and constant software development (Hill, 2009). Getting more functionality for less money is irresistible for not only funding-strapped educational institutions, but American corporations as well. Gartner Group's Vice President Darryl Plummer estimates that $8 out of every $10 spent on technologies in corporations goes to maintenance rather than innovation (King, 2009). Merrill Lynch estimates that within the next five years the annual global market for cloud computing will surge to $95 billion (King, 2009). In a May 2008 report, Merrill Lynch estimated that 12% of the worldwide software market would go to cloud computing in that period (King, 2009). Microsoft has made cloud computing one of five priorities for fiscal 2009, according to a memo from CEO Steve Ballmer (King, 2009). "The focus of innovation indeed seems to be ascending into the clouds" (Hayes, 2008). Google® Apps is uniquely positioned for educational sectors in relation to alternative cloud vendors such as IBM, Dell, Amazon, and Hewlett-Packard (Hill 2009). While Google® Apps is viewed as an evolutionary step towards efficiency and scalability, some question whether privacy and security concerns are sufficiently addressed (Hayes, 2008).

From the student perspective, the free Education Edition of Google® Apps provides learning tools such as Gmail, word processing/spreadsheet/presentation software, calendar, chat, and video/photo processing (Oishi, 2007). From an instructor perspective, the Google® Apps ecology reduces "transactional distance" (Moore, 1992) via its improved communication and collaboration tools. In addition, links to computer test generators and grading systems recoup potential time expended in mundane grading tasks and potentially free the instructor to spend more time with students. In one study at Minnesota State University (N=73), computer-assisted grading yielded a 200% efficiency gain over hand grading, a 300% efficiency gain over hand grading with rubrics, and 350% efficiency gain over typing feedback into the Learning Management System, with no attenuation of student satisfaction with respect to feedback quality (Anglin, 2008). Integrating homework tutorial systems such as masteringphysics® into the learning environment extends the potential tutor list to include the computer tutor, and extends the workday to after-school hours. From a management perspective, schools, universities, and classrooms register their private domain with Google® to install the Education Edition of Apps. This provides a secure environment with administrator functions for user management, firewall, email filtering functions, and more (Oishi, 2007).

Google® Apps provides the collaborative framework necessary for mastery learning of secondary science. This technology framework facilitates the essential mastery learning components of frequent feedback, correctives, and assessments. Google® Apps enables the instructor to have increased personal contact with students and increased efficiency by several means. Google® Apps provides Gmail, chat, video chat, collaborative calendaring and documents (word processing, spreadsheet, and presentation), content management, easy linkage to web tutorials, video lectures, and assessment tools (i.e., test generators with automatic grading), and domain management and control tools.

Web 2.0 is a polymorphic term coined by publisher and champion Tim O'Reilly in 2006, and its range of applications includes collaboration and communication tools such as blogs and wikis. The core idea behind Web 2.0 is that "the web and its structure should support people in their work; it should be a medium for communication between people" (Rollett, 2007, p. 95). Web 2.0 technologies, including Google® Apps, empower the instructor to meld web resources, including RSS feeds, to class websites (Rollett, 2007). "Many members of the Web 2.0 community regard it as their moral right to remix content, which of course flies in the face of traditional business models based on restricted access to intellectual property" (Rollett, 2007, p. 97). The Open Access movement, such as MIT's Open Courseware (http://mitworld.mit.edu), Creative Commons (http://creativecommons.org), and Science Commons (http://sciencecommons.org), empower instructors to combine materials from different sources (Rollett, 2007). The capstone environment embeds many open resources in the customized framework of the class website.

Within the connected Web 2.0 learning environment, “instructional strategies” give way to “learning environments,” because just as Friedman (2008) expressed so influentially, “the world is flat,” and that includes a flattening of education. Traditional, vertical, “transmission” modes of learning are being supplanted by horizontal, networked, learning “ecologies” (Downes, 2005; Siemens, 2008).

Summary of Literature Review

The capstone focus on self-directed and supported mastery learning evolved through extensive literature review and was anchored around Bloom’s landmark article on mastery learning (Bloom, 1968). Decades of research lend support for mastery instructional practices to “shift the bell curve” and enable more students to master concepts given sufficient time and feedback with correctives (Bloom, 1968; Gagne, 1988; Guskey, 2007; Kulik, Kulik & Bangert-Drowns, 1990). The prevailing and resonating themes from the literature that drove the capstone project were 1) traditional teacher-led instruction is largely ineffective (Crouch, 2001; McDermott, 2001; Meltzer & Manivannan, 2002); 2) blended learning is more effective than either face-to-face or wholly online instruction (US DOE, 2009); 3) self-directed learning, like mastery learning, is interactive and involves the gradual release of control from the instructor to the student (Abdullah, 2001; Gibbons, 2002); 4) interactive engagement and peer instruction have strong PER literature support (Crouch & Mazur, 2001; Hake, 1998, 2007; Meltzer & Manivannan, 2002); 5) research-based computer tutors such as masteringphysics® produce learning gains equivalent to an expert tutor (Morote & Pritchard, 2010; Ogilvie, 2001); and 6) decades of educational technology research by MIT's Teaching and Learning Lab have produced impressive learning gains in physics and other branches of science (Breslow, 2007; Dori, 2007; Lipson, 2001). The result of these extensive and sometimes disparate readings was a coalescence of self-directed learning, mastery learning, guided inquiry, educational technology, and blended learning ideas into the form of a self-directed learning contract called the VOLO in conjunction with multiple formative tests to serve as the core of the capstone learning environment, more fully described in Chapter 3. Chapter 4 will present results and Chapter 5 will discuss the findings and conclusions.

Table 2-1. Collection of noteworthy instructional interventions within physics education research (PER) literature

Category	Instructional Strategy	Synopsis and Capstone Integration	Reference
Mastery learning using computer tutors	masteringphysics®	Computer tutors provide feedback and Socratic questioning necessary to build problem-solving skills in physics students and are available 24x7. Learning gains measured in 2-sigma range. In addition, computer tutors provide feedback to instructors, highlighting areas in which to focus instruction. This capstone integrates masteringphysics® as the primary computer tutor.	Morote & Pritchard, 2009; Ogilvie, 2001; Warnakulasooriya, 2005
	University of Colorado at Boulder's PhET project, MIT's PIVoT and TEAL projects	Well-designed interactive simulations can be an engaging and effective tool for learning physics, especially when scaffolded by semi-structured activity plus feedback and assessment. This capstone integrates PhET.	Wieman, 2008; Breslow, 2007
	Interactive simulations	Minds on Physics (MOPS) curriculum developed by the Physics Education Research Group at the University of Massachusetts is built on constructivist principles and is interactive and increases in complexity, requiring effort on the learner's part.	Gerace, 1999
Modeling	Teaching methodology that rests heavily on pedagogical expertise	As few as seven models, for instance conservation of energy, can unify physics instruction and organize developing schema. Students are familiarized with the models, then evaluate new problems and apply the appropriate model to the problem. High school physics teacher Malcolm Wells developed the modeling method of instruction and his students achieved FCI performance equivalent to Harvard physics students. Modeling is highly regarded within the Physics Education community, but is not emphasized within this capstone project. It is mentioned here because the same Arizona State PER group (headed by Hestenes) that created modeling also created the FCI assessment and because it is a future emphasis for the capstone site.	Wells, Hestenes & Swackhamer, 1995

Table 2-1. Continued

Category	Instructional Strategy	Synopsis and Capstone Integration	Reference
Interactive engagement	ConcepTests, peer instruction, and response systems Small group tutorials and problem solving	Active learning is sought even in large lectures. Techniques include short 15-minute lectures interspersed with short ConcepTests, which challenge students to apply concepts collaboratively, cast votes for best answer, and then receive immediate feedback. Such interaction guides the content of the ensuing lecture, as the instructor focuses on common misconceptions. "Students learn very little from traditional lectures.... Students develop complex reasoning skills most effectively when actively engaged with the material they are studying" (Crouch & Mazur, 2001, p. 970). Given the small class sizes in this capstone and the predominance of small-group work, interactive engagement is integrated.	Noteworthy investigations include the impact of peer instruction (Mazur, 1997; Crouch & Mazur, 2001), interactive engagement (Hake, 1998; Meltzer, 2002; Reddish, 1999), small tutorial groups (Hake, 1998), and cooperative problem solving (Heller, 1992).
Active learning	Laboratory explorations may be digital simulations, or simple to elaborate hands-on exercises.	The TEAL project at MIT doubled test performance in an electromagnetism course, but required years to perfect. Specially designed learning spaces allow nine students to sit at a round table with a PC on which two- and three-dimensional visualizations and simulated laboratory data are generated. The capstone does not employ such carefully designed and orchestrated learning spaces as TEAL, but approaches something similar using open resources and hands-on experiments.	Breslow, 2007

Table 2-2. Learning gains cited in literature for various educational interventions

Intervention ** Interventions addressed in this capstone.	Sigma Change	Reference
One-to-one tutor**	2	Bloom, 1984
Computer tutor**	1.76, 2	Corbett, 2007; Morote & Pritchard, 2009; Ogilvie, 2001
Reviewing prior material**	1.2	Bloom, 1984
Study skill instruction	1	Bloom, 1984
Improved time on task**	1	Bloom, 1984
Mastery learning**	0.5 - 1	Bloom, 1984; Kulik, Kulik Bangert-Drowns, 1990
Classroom participation**	1	Bloom, 1984
Cooperative learning**	0.5-0.8	Bloom, 1984; Johnson, Johnson & Stanne, 2000
Graded homework**	0.8	Bloom, 1984

Table 2-3. Shifts in thinking between teacher-directed and student-directed learning (Gibbons, 2002)

In teacher-directed learning, the teacher	**In student-directed learning, the teacher**
Decides the course goals and the content to be studied	Teaches students to set their own goals and eventually choose what they will study
Presents course content to students in lessons	Teaches students the goals and processes involved in setting goals, making plans, and initiating action
Sets exercises and assignments for study	Negotiates student proposals for learning and acting
Monitors completion and assesses accuracy of student work	Guides students through self-directed challenge activities
Tests and grades student performance	Reviews students' assessment of their work

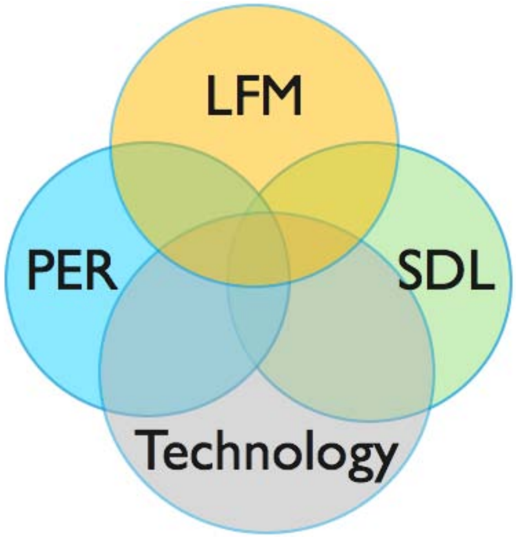

Figure 2-1. The literature review of Chapter 2 explores these four conceptual areas: Physics Education Research (PER), Learning for Mastery (LFM), Self-Directed Learning (SDL), and Technology.

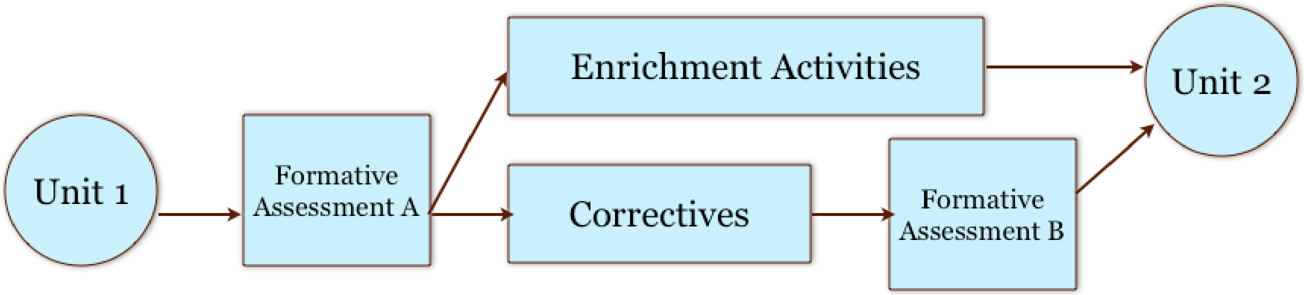

Figure 2-2. Mastery learning is a feedback-corrective response instructional strategy that uses formative assessments to guide learning.

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

The first chapter presented the challenge of improving American science education in the context of an increasingly competitive, technology-driven world (Friedman, 2008). This is an overwhelming problem, but an achievable first step in its solution is to improve science education one classroom at a time. An instructor could pursue myriad angles in the pursuit of better learning outcomes, and a literature-based rigor with careful reflection drove this author towards the self-directed mastery learning approach. The broad problem of improving science education then focused on an instructional design challenge to create a supported and assessment-based self-directed mastery learning environment.

This capstone study was conducted over four weeks in two honors physics classrooms in a private high school in Fort Myers, FL (N=24). The course design entailed approximately 25% FTF/whole-class format of traditional lecture, problem-solving practice, and laboratory experiments, and 75% SDL rendered through a Google® Apps infrastructure. The overarching goal was to build mastery of conservation of energy concepts by incorporating SDL such that the instructor could spend more time in one-to-one tutoring while also providing supplemental peer and computer tutors. During the self-directed portion of the study, students were given three required activities and told to choose two more learning activities from a limited array presented as the VOLO. The VOLO activities were managed by the student within the class website. The SDL choices of students, i.e. their time investment in learning activities and support structures, were tracked through daily Time Tickets, which were rendered using Google® Forms (Appendix A) and fed directly into a spreadsheet. Computer tutor time was logged by the masteringphysics® system.

Figure 3-1 provides an overall view of the capstone's self-directed and supported mastery learning environment. The overall technology infrastructure was Google® Apps, which provided improved communication between instructor, learner, and peers. Within Google® Apps, each learner maintained a personal web page (box on the left), which contained his or her VOLOs, blogs, and e-portfolio. The VOLO appears as the tic-tac-toe box in the lower left corner of Figure 3-1. The three tutor types are represented in the figure (note computer tutors are embedded in the VOLO box). Weekly assessments were part of the mastery learning process, which was a cycle of formative assessments with associated feedback and correctives.

Context

The two sections of honors physics (N = 24) were 50/50 male/female and 20% minority. The minority students were of Asian descent. Less than 10% of the students were on economic scholarship. Student learning styles were determined before the capstone study using the Visual-Auditory-Read/Write-Kinesthetic (VARK) Survey (http://www.vark-learn.com/english/page.asp?p=younger). VARK results indicate 33% of the students were kinesthetic learners, 25% were auditory, 24% were visual, and 17% were read/write-oriented.

Classroom resources included a technology lab equipped with 16 networked PCs and a science lab. On a typical day students chose between the classroom or these other two locations to work. Every student also had a PC or a personal laptop at home. Every student owned a scientific calculator and had purchased a masteringphysics® registration at the start of the school year, which functioned as the homework tutorial system and served as the primary "computer tutor." The class textbook was *Physics: Principles and Problems*. (2009). Columbus, OH: McGraw Hill. The class website was http://tinyurl.com/ecsphysics and can be viewed through username *capstone* and password *capstone*.

Research Design

The central problem for this study was to investigate whether self-directed mastery learning improved conceptual understanding of physics. The central research questions of the capstone study were:

RQ #1 - What SDL activities did honors physics students choose in their self-directed mastery learning environment?

RQ #2 - How many students achieved concept mastery when SDL activities were infused into the honors physics classroom for a given time period, and how did they spend their time?

RQ #3 - Did successful and unsuccessful students perceive the self-directed mastery learning environment differently?

These three research questions are aligned with corresponding data sources and analyses that answer the questions, as shown in Table 3-1.

RQ #1 data collection and analysis: The first question about SDL activities that students chose was addressed using VOLO selection and Time Ticket data. Bar charts of these data revealed the most popular and time-intensive activities/supports.

RQ #2 data collection and analysis: The second question separated the students into two groups, successful and unsuccessful, according to whether they had cleared the unit test with at least an 80% given up to four tries during the timeframe of the learning unit. The SDL activities of successful versus unsuccessful students were compared on a time basis and this data was presented in a bar chart and data table.

RQ #3 data collection and analysis: The final research question about student perceptions was addressed using post survey data that was Likert-style as well as free-response. Three categories of questions were evaluated: SDL readiness, basic problem solving and development of expert thinking about physics, and perceptions of the self-directed mastery learning environment. The average Likert scores were reviewed and the Mann-Whitney U test was run to determine statistical significance of the differences in responses between successful and unsuccessful students. These results were summarized in Tables 4-2 and 4-3.

Pilot Study

Several implementation decisions were made as a result of a pilot study conducted during the first semester of the year-long project. In the pilot study, students' average test scores were higher on the second attempt of the test (typically a 20% gain), but then went down on the third and fourth tries. Students were strongly encouraged to retake tests until they reached an 80%, but it was not mandated because the instructor felt compelled to move forward with the majority. Students could be content with their grade and stop trying. The challenge remained to help the struggling students achieve mastery in the capstone study, which occurred early in Semester 2.

The capstone project incorporated several new elements based on pilot study feedback and the need to collect more data:

The percentage of whole-class face-to-face time was increased. Based on student feedback from Semester 1, students desired more exposure to example problem solving in a whole-class setting. In Semester 2, the percentage of whole-class instruction was increased to approximately 25%. More classes began with brief (10-15 minutes) whole-class instruction, which provided an opportunity to help with challenging problems from the homework set and allowed a second and third presentation of key concepts.

Students filled out Time Tickets each day. Time-tracking by students occurred through Time Tickets that were rendered using Google® Forms and automatically fed into a Google® Spreadsheet (Appendix A). Students specified how many minutes they engaged in each VOLO activity each day and how many minutes they used the three tutor supports. Knowing minutes of each SDL activity informed the instructor about which activities were most/least time intensive and popular. It was possible the successful students needed little support and the unsuccessful students needed much support, such that an inverse relationship would emerge or perhaps a positive relationship or perhaps none at all. Also, since the purpose of the VOLO design was to free the instructor for more one-to-one help with students, it was important to determine if that goal was achieved.

A student post survey was added. Students were surveyed at the conclusion of the learning unit (Appendix B). The goal of the survey was to appraise student attitudes about SDL, LFM, and learning physics.

Infrastructure

Google® Apps platform

The design of the self-directed and supported mastery learning environment began in summer 2010 with the creation of a dedicated Google® Apps for Education domain for the capstone classroom (http://tinyurl.com/ecsphysics). This freed the instructor from internal IT restrictions and provided the essential Web 2.0

communication (Gmail, chat, Groups) and collaboration (Groups, calendar) tools. It also provided site management, security, word processing, presentation, spreadsheet, drawing, imaging, video, and work flow and content management functions. The instructor created a class roster, gave each student a Gmail account, and gave the students editor status on the class website. The instructor then created a personal page for each student and embedded a file cabinet on their page for their e-portfolio items. One of the students' first class assignments was to personalize their web page and create a physics learning blog and embed it on their page. Students were also required to take the VARK (visual-auditory-read/write-kinesthetic) learning style survey and embed their results on their personal page for future reference. Figure 3-2 is a snapshot of an individual student page. Notice the prominent VOLO boxes, which are the student's learning contracts, and which are detailed below. The instructor ported over the previous course website and established a navigation bar to link to each learning unit.

VOLOs

VOLOs provided a differentiated pathway to learning by allowing students to choose their learning pathway according to their individual learning styles and interests. The VOLO contained eight learning activities and one wildcard activity that permitted the student to propose how he/she would learn the concepts (Figure 3-3). Some VOLO tasks were required and are highlighted in Figure 3-3, specifically the Pendulum-Box Bash Lab, masteringphysics®, and PhET Energy Skatepark. A great deal of thought and care was taken in the selection of VOLO activities. The instructor was cognizant of appealing to different learning styles and also applied years of experience with PER resources. Helpful tools for finding qualified resources included such excellent websites as http://merlot.org and http://learningscience.org/. The VOLO grade was derived from this simple rubric: five tasks completed was a 100%, four units completed was an 85%, three units completed was a 60%, and two units completed was a 30%.

Instructional Strategy

The capstone crafted a four-week instructional unit that blended whole-class FTF and self-paced online learning as shown in the unit schedule (Figure 3-4). Instruction began in a whole-class setting and involved three days of conceptual/problem-solving lecture, an inquiry activity about pendulums, followed by the PBB Lab. The VOLO for the unit was then revealed (Figure 3-3), and students contracted with the instructor for the five tasks they would undertake over the next two weeks to master the concepts. The “contract” consisted of students pasting the VOLO box onto their personal web page and indicating their choices. Whole-class meetings interspersed the next two weeks of SDL work. The team-based Rube Goldberg project consumed the third week of the unit (Figure 3-4).

Bates & Poole's (2003) book on blended learning facilitated the instructional design process through a series of very practical questions, which provided a framework for complete development of the instructional strategy:

What are the intended learning outcomes for the course? How will they be assessed? The overall goal of the course was to prepare learners for college physics. The learning goals for the conservation of energy unit were to use a model to relate work and energy; calculate kinetic, potential, and work energy; identify how potential energy is stored in a pendulum and spring; show that conservation of energy laws hold in pendulums and springs; solve problems using conservation of energy; design and build a Rube Goldberg machine that folds a piece of paper twice, incorporating at least five energy conversions in the process; design a virtual roller coaster that meets amusement park requirements; identify cases in which conservation of energy laws do NOT apply. The standards addressed in the learning unit included Standard Number 1.0 - Mechanics: The student will investigate the laws and properties of mechanics; investigate the definitions of force, work, power, kinetic energy, and potential energy; and analyze conservation of energy including friction. Unit 11 assessments included multiple unit tests including a pre-test, the Rube Goldberg project, and VOLO completion.

How much time each week do students have to devote to this course? How can the teaching best be organized over the weeks? Students had typically 52 minutes of class time each day. Because the materials and videos were available online, nothing precluded students from working outside of class. Figure 3-4 illustrates the four-week cycle, which kicked off with three days FTF instruction that created a big picture view of the unit and introduced important concepts. VOLO choices were revealed. The three days also included the whole-class pendulum inquiry activity followed by the Pendulum-Box Bash Lab. Common activities during the SDL time were required activities such as masteringphysics® and test review with the instructor. Whole-class summaries and problem solving were common at the beginning of many class periods. Students were free to work individually or in groups. The Rube Goldberg project consumed the third week.

Could technology enable achievement of learning outcomes? Technology enabled achievement of learning outcomes. Computers and a science lab were always available. The class website was the central hub of all class activity and provided a

24x7 repository and central communication portal. Google® Apps streamlined communication and collaboration and provided content management functions and office suite tools. The seamless integration of web resources was essential to computer-tutor function. Students completed daily Time Tickets. Student choice was preserved with the VOLO scheme (Figure 3-3). VOLO choices were blended with respect to technology or traditional and with respect to learning styles. Rather than the instructor making the technology choice for the student, the student chose his or her preferred learning pathway, with or without technology.

What are the main presentation requirements for the content? What media and technologies could best meet these presentation requirements? A class field trip to an amusement park preceded the learning unit and provided the real-world framework for the conservation of energy investigation of roller coaster design. The Pre-Test was administered on Day 1. The instructor gave a Powerpoint® lecture that reviewed work and emphasized that work was a form of energy. To introduce the ideas of conservation of energy, Roller Coaster Tycoon® was showcased as the unifying theme and as an illustration of various energy forms. Actual data collected during the field trip was used to compute kinetic and potential energies. The instructor demonstrated how to determine the amount of potential energy at the top of the ramp and the amount of kinetic energy at the bottom, then suggested in-between values could be determined using the Work-Energy Theorem. This was reinforced by use of http://physicsclassroom.com animations of roller coasters, which included bar charts indicating the kinetic, potential, and total energies at each moment.

On Day 2, after review of the previous day's energy-conversion ideas, a pendulum demonstration with accompanying virtual pendulum animation (http://www.elmer.unibas.ch/pendulum/index.html) illustrated how the pendulum alternated between 100% potential and 100% kinetic energy. The various factors that might influence the period of the pendulum were discussed. Giant pendulums were attached to the classroom ceiling and students were told to isolate those factors that influenced the period of the pendulum. At the conclusion of the class period, the instructor wrote students' suggestions on the board, then revealed the pendulum equations. The instructor discussed the setup and purpose of the next day's lab, the PBB Lab. VOLO contract choices were presented and clarified.

On Day 3 students conducted the PBB Lab, developed at Ohio State University (Zou, 2000). The basic setup of the lab consisted of a sandbag pendulum striking an ordinary cardboard box. Students measured how high the sandbag was raised and how far the box traveled. The purpose of the lab was to consider energy losses and conditions in which conservation of energy laws do not apply. A whole-class discussion followed the lab. The ideas presented in the PBB Lab were embedded in the unit tests (a sample test is shown in Appendix C).

Approximately 10 days of independent and small-group work followed as students engaged in their VOLO work. The VOLOs provided a variety of technology-rich, traditional, and hands-on activities for students. Everyone had already completed one VOLO requirement, namely the PBB Lab. The PhET Energy Skate Park animation was the second required activity and continued the roller coaster theme and challenged the students to manipulate variables to see the effects on energy types. The third required activity was masteringphysics®, which required approximately 106 minutes to complete and consisted of 19 problems involving work, kinetic energy, potential energy, springs, pendulums, skate boards, bullets, slides, amusement parks, and more. As for VOLO choices, the learner selected from an AP-level lab which tested Hooke's Law (a visual and kinesthetic choice), another pendulum lab which found the acceleration of gravity (a visual and kinesthetic choice), Roller Coaster Tycoon® software design of a roller coaster with specified parameters (visual, auditory, and kinesthetic choice), a rather simple online KE ⇔ PE quiz (read/write choice), and reading Chapter 11 and taking the associated standardized test (read/write choice). Approximately every week students took unit tests until they achieved at least an 80%.

Brief whole-class meetings interspersed the SDL phase to address troublesome areas in the masteringphysics® problem set and to guide activities. For instance, a spring was suspended from a cross-bar with a mass attached. The instructor illustrated the periodic motion of the spring-mass system and how it alternated between 100% potential and 100% kinetic energy. These ideas were part of the masteringphysics® homework assignment. Parameters were manipulated physically and virtually (http://phet.colorado.edu/en/simulation/mass-spring-lab) to demonstrate how changing the spring constant, mass and amplitude impacted the period. Students learned how to experimentally determine the spring constant. Students computed kinetic and potential energies for the spring.

The Rube Goldberg project was a grand team effort that challenged the students to think about energy conversions and apply the principles learned with a hands-on activity. The Rube Goldberg challenge was to fold a piece of paper twice by the most inefficient means possible. The project was graded according to simple criteria: Did the team incorporate at least five energy transformations in the process of folding a piece of paper into quarters? Points were deducted if human intervention was necessary to complete the process. Points were also deducted for non-contribution, if necessary. Because the Rube Goldberg project did not differentiate between students (because all team members shared the same grade), the activity was not included in the data analysis.

What kind of interaction will help students acquire the content and develop the skills for this course? What technologies will best facilitate these interactions? Students received support from instructor, peer, and computer tutors. Feedback was to be timely and individualized. Through the use of a Web 2.0 class website, which made students not only passive consumers but also authors and communicators, higher levels of engagement were expected (National Survey of Student Engagement, 2009).

How will the student be assessed? The balance of the student's course grade was 45% test, 45% VOLO completion, and 10% homework (submitting daily Time Tickets and post survey). This overall assessment balanced concept mastery (test scores) with diligence (VOLOs and homework) and collaboration (Rube Goldberg project, PBB Lab).

Data Collection

Unit Tests

Frequent formative assessments are central to mastery learning philosophy, proved troublesome in Semester 1, and were streamlined in Semester 2. Unit tests were multiple paper versions that were hand graded (a sample test is shown in Appendix C). Unit tests were similar, not the same, and shortened so they could be completed in 30 minutes, which ensured that the instructor could quickly grade and review them with the student. The limit on the number of test retakes was four. Students retained their best test score; it was not averaged with previous attempts. The SDL structure provided the flexibility for students to retake a test during the regularly scheduled class period.

SDL Activities

Students were assessed on completion of VOLO components. A VOLO activity was complete when the student scored at least an 80% on the activity. The student needed to complete five VOLO activities to receive a 100% for the VOLO grade. Masteringphysics® was a required activity and was automatically graded. One lab, the Pendulum Box Bash Lab, was required and was completed in small teams. Each member received the same grade when the report was submitted. The third required VOLO activity was the PhET Energy Skate Park simulation, completed on an individual basis using a worksheet. The remaining VOLO activities were according to student choice, and students communicated the completion of their work through their personal web pages. As indicated in Figure 3-3, the VOLO options for this unit were: Roller Coaster Tycoon®, KE ⇔ PE quiz, find “g” Lab, virtual spring lab, read Chapter 11 and answer standardized test questions, or a wildcard activity of their choosing (with permission). All VOLO activities were counted and also tracked according to minutes invested in the activity. In this way, the instructor could note the most time-intensive and popular activities. To identify which learning activities were most effective in building concept mastery, the SDL choices and time investment of successful and unsuccessful students were compared.

A student could choose to use expert, peer, or computer tutor support. The Time Ticket specified which types of support, if any, students used and for how many minutes. Computer tutor times (minutes spent using masteringphysics®) were logged by the system and accurately known. Peer and expert times were gathered through Time Tickets and were less accurate than computer tutor times.

Post survey

Student perceptions of the self-directed mastery learning environment were captured through a post survey and analyzed (Appendix B). The first part of the survey focused on SDL, attitudes about learning physics, and learning environment preferences. The post survey was derived from three sources in addition to custom questions about the capstone's learning environment. Several questions were derived from Guglielmino's (1977) Self-Directed Learning Readiness Scale (SDLRS), Halloun's (2001) Views About Sciences Survey (VASS), and the Colorado Learning Attitudes About Science Survey (CLASS, 2006). Example Likert-scaled items included "I cannot learn physics if the teacher does not explain things well in class", "I enjoy solving physics problems," and "I do not invest time understanding the derivations of equations."

The second part of the survey used the following four open response questions to explore preferences of learning activities and support structures particular to the capstone's learning environment:

1. Three VOLO activities were required – masteringphysics®, PhET Energy Park, and the Pendulum-Box Bash experiment. Identify the other two VOLO activities that you chose, explain why you chose them, rate how much you enjoyed them, and rate their usefulness to your learning. Use the scale of 1 (low) to 5 (high).
2. Describe how accessible your teacher was in meeting your learning needs, and rate the quality of that support on a scale of 1 (low) to 5 (high).

3. Describe how accessible your peers were in meeting your learning needs, and rate the quality of that support on a scale of 1 (low) to 5 (high).

4. If you had a choice of two tools or resources to use to learn physics, what would you pick and why?

Data Analysis

Quantitative data sources for this capstone are listed in Table 3-1 and included unit test grades, Time Ticket data, masteringphysics® times and scores, VOLO activities chosen and completed, plus the post survey data. Data analysis was broken down according to the three research questions as follows:

RQ #1: What SDL activities did honors physics students choose in their self-directed mastery learning environment? Completed VOLO activities were tallied from student web pages, and the minutes invested per activity were tracked using Time Tickets. These summary data provided perspective of the most/least popular or time intensive activities. Minutes invested with expert and peer tutor were tracked using Time Tickets, and minutes invested with masteringphysics® were logged by the system.

RQ #2: How many students achieved concept mastery when SDL activities were infused into the honors physics classroom for a given time period, and how did they spend their time? To determine the impact of SDL activity choices and time on concept mastery, the number of students who cleared the unit test given four tries was determined. Then the students' time allocation per SDL activity data was separated into two groups, successful and unsuccessful; side-by-side comparisons were made and similarities and differences were noted.

RQ #3: Did successful and unsuccessful students perceive the self-directed mastery learning environment differently? The post survey was designed to probe students' perceptions of the self-directed mastery learning environment using Likert ratings and free-response questions. A side-by-side comparison was made between the average Likert ratings of successful versus unsuccessful students and Mann-Whitney U tests were conducted to determine statistical significance. In addition, free responses were evaluated in successful versus unsuccessful groupings.

Summary

To develop mastery of conservation of energy concepts for the 24 honors physics students at a private high school in Fort Myers, FL, this capstone project revived a tried-and-proven instructional strategy – mastery learning (Bloom, 1968; Guskey, 2010) – in a self-directed, technology-enabled learning environment. Self-direction was incorporated because it is recommended as an important life skill and can contribute to more meaningful learning as learners follow their interests, learning styles, and skill sets (Abdullah, 2001; Partnership for 21st-century skills, 2009). The focus of the project was to determine the types of learning activities and support structures learners preferred and analyze how SDL activities impacted concept mastery. Data collected included Time Tickets, masteringphysics® time logs, VOLO choices, and post survey data. Data analysis pursued the nature of the relationship between SDL activities and concept mastery. Attitudes about SDL, learning physics, and the self-directed mastery learning environment were assessed using a survey and perception differences between successful and unsuccessful students were explored.

Table 3-1. Data sources and analyses that answer the research questions

Research question	Data Sources	Data Analysis
What SDL activities and support structures did honors physics students choose in their self-directed mastery learning environment?	Time Tickets specified time spent in each SDL activity Completed SDL activities records on personal web pages Detailed time data from masteringphysics® computer tutor	Average number of SDL activities completed Minutes invested per SDL activity Average educational and enjoyment ratings of VOLO activities
How many students achieved concept mastery when SDL activities were infused into the honors physics classroom for a given time period, and how did they spend their time?	Number of students who achieved mastery level (80%) on unit test within four tries. Time Tickets specified time spent in each SDL activity for successful students Completed SDL activities were recorded on personal web pages for successful students Detailed time data from masteringphysics® computer tutor for successful students	Number of students who cleared unit test SDL activities completed for successful students Minutes invested per SDL activity for successful students
Did successful and unsuccessful students perceive the self-directed mastery learning environment differently?	Student post survey	Spreadsheet of average Likert responses of successful versus unsuccessful students per post survey question Mann-Whitney U Test of statistical significance of responses Favorite resource list of successful versus unsuccessful students Table of Likert ratings from successful and unsuccessful students of three support structures

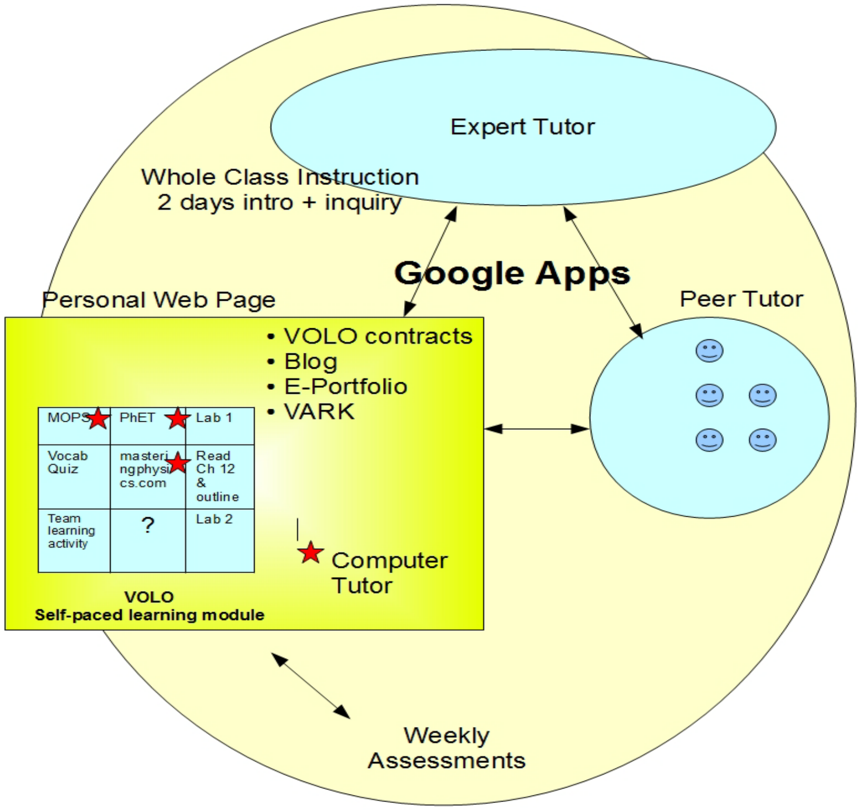

Figure 3-1. Overview of the capstone design of a supported and assessment-based self-directed mastery learning environment.

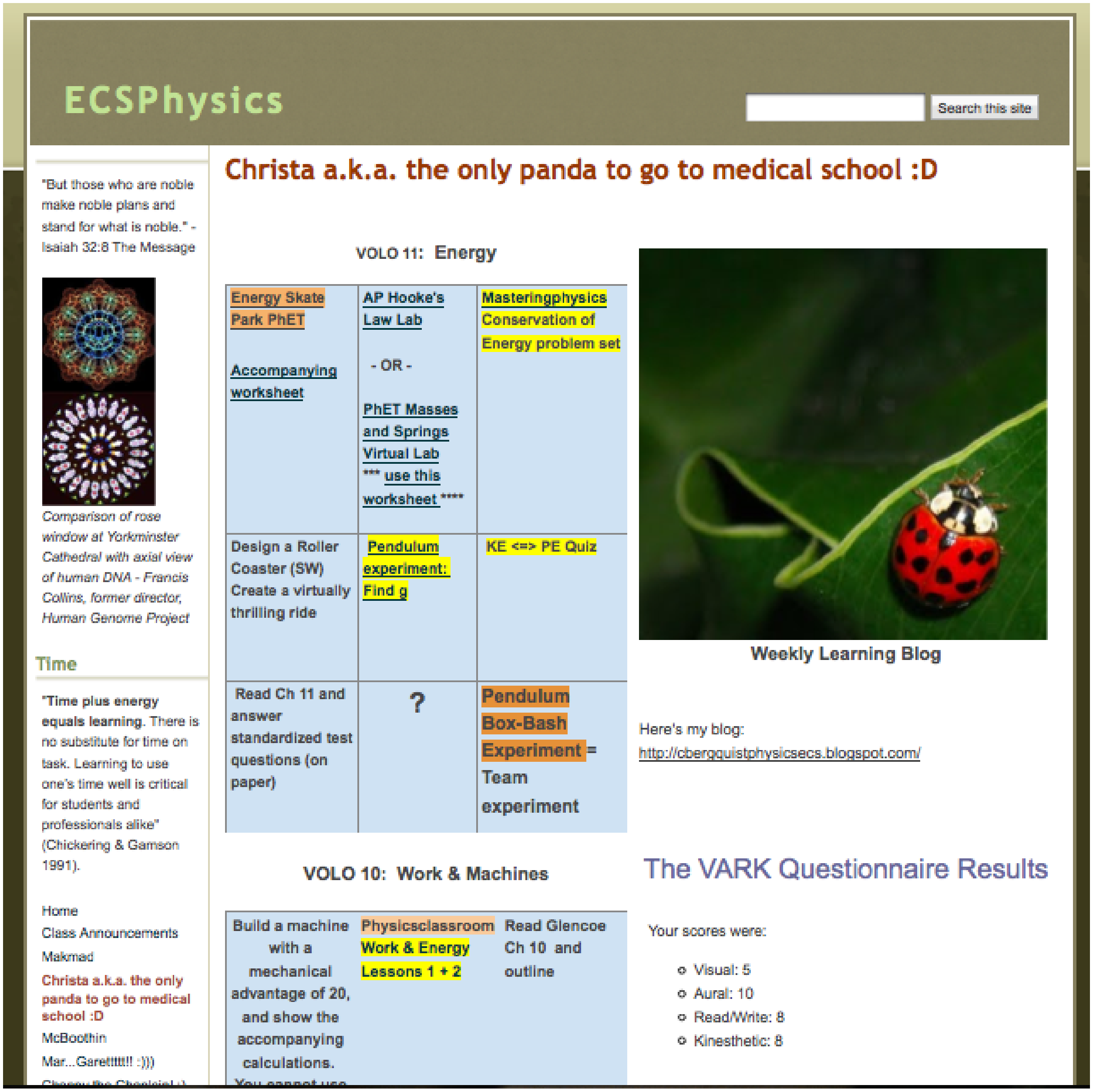

Figure 3-2. Snapshot of a personal student web page in the class website.

Conservation-of-Energy Learning Unit

2 Tests: Rube Goldberg Project & Ch 11 Test

required

Rubric:
5 boxes = 100
4 boxes = 85
3 boxes = 60
2 boxes = 30

Energy Skate Park PhET Accompanying worksheet	AP Hooke's Law Lab Use the graph above as a guide, and use at least two different springs for the experiment. Answer the questions for part 1. Then use a thick rubber band to generate a new F vs. x chart, and answer the questions for part 2.	Masteringphysics Conservation of Energy problem set
Design a Roller Coaster (SW) Create a virtually thrilling ride	Pendulum experiment: Find g	KE <=> PE Quiz
Read Ch 11 and answer standardized test questions (on paper)	?	Pendulum Box-Bash Experiment = Team experiment

Figure 3-3. The VOLO for the conservation of energy unit shows three required activities –PhET, masteringphysics®, and PBB Lab.

ECSPhysics Feb 2011 (Eastern Time)

Mon	Tue	Wed	Thu	Fri
31	1	2	3	4
Foucault animation Pre-Test Whole-class lecture 8am - Start Unit 11 -	Inquiry lab - Pendulums Review Pre-Test	Whole class: Pendulum	Start VOLO work Whole class: Review Whole-class: Monkey on a	VOLOs
7	8	9	10	11
1/2 day VOLO 1/2 day whole-class roller	Test 11.1 VOLOs thereafter	Review Test 11.1 VOLOs thereafter Whole-class: Rube	VOLOs	VOLOs
14	15	16	17	18
8am - Unit 11 - Rube Goldberg				
21	22	23	24	25
No school!	Test 11.3 VOLOs thereafter	Olive Garden catered Review 11.3 Test VOLOs	Test 11.2 Whole-class: Springs &	FCI Wrap-up VOLO 11

Figure 3-4. Instructional sequence during the four-week unit. Note the time allocation of approximately 25% whole-class versus 75% SDL.

CHAPTER 4
RESULTS

The capstone results focus on SDL activities, defined as time allocation choices made by the student and include both VOLO activities and support structures. Three VOLO activities were mandatory - masteringphysics®, PBB Lab, and PhET Skate Park – and the rest were elective. To reiterate, the three support structures were the instructor (expert tutor), masteringphysics® (computer tutor), and the peer tutor. The minutes invested per activity were tracked using Time Tickets with the exception of the computer tutor times, which were collected from the more reliable source of the masteringphysics® time logs. The results for this chapter are organized according to the three research questions.

SDL Activities Chosen and Completed (RQ #1)

Completed SDL activities were tallied from student web pages and are displayed as a bar chart in Figure 4-1. All students participated in the two mandatory SDL activities and all students used peer and expert tutor support. The most popular elective VOLO activities were Roller Coaster Tycoon® (16 students chose), the KE ⇔ PE quiz (15 chose), read Chapter 11 and take standardized test (6 chose), the PhET springs lab (3 chose), and the Find “g” experiment (4 chose). According to the post-survey free responses, the top reasons stated (in rank order) for these selections were (1) quick and easy, (2) enjoyment, and (3) educational. VOLO completion rates were good - 20 of 24 students completed all five activities and received a 100% VOLO grade, 3 students completed 4 activities for an 85% grade, and 1 student completed 2 activities for a 30% grade. The whole-class PBB Lab counted for a VOLO activity for every student. Table 4-1 associates the VOLO activities with students’ perceptions of their educational and enjoyment value. The most educational activities were two labs with low participation (one and two students completed) and the most enjoyable activity was Roller Coaster Tycoon® (score of 4.3).

Figure 4-2 presents SDL choices on a time basis and it is evident that minutes invested with peer tutors (203 minutes) dwarfed everything else. The second most time-intensive SDL activity was masteringphysics® (118 minutes), followed by time spent with the instructor (84 minutes). Preparing and retaking tests consumed an average of 45 minutes per student, and PhET Skate Park and Roller Coaster Tycoon® both consumed an average of 37 minutes per student. The Find "g" lab consumed an average of 21 minutes, and all the other activities required less than 10 minutes to complete.

Choices and Time Allocation of Successful Students (RQ #2)

Students could retake the unit test up to four times during the learning unit in an effort to achieve at least an 80%. At the close of the learning unit, seven students cleared the unit test, and 17 did not (Figure 4-3). It is interesting to note that one of the successful students was a minority student of Asian descent and two were on economic scholarship. Henceforth, the seven students who cleared the unit test are grouped as the "successful" students, and the 17 students who did not are grouped as the "unsuccessful" students. These two groups are compared with respect to their SDL choices, time allocation, and perceptions of the self-directed mastery learning environment.

Figure 4-4 is a repeat of Figure 4-2 (Minutes invested per SDL activity), but is split into successful and unsuccessful groups. It is clear that successful students invested an average of 25% more time than unsuccessful students did per SDL activity, and particularly more time was invested in doing the masteringphysics® homework assignment, retaking tests, and tutoring with the instructor. In fact, the only SDL activity in which successful students invested less time than unsuccessful students was in Roller Coaster Tycoon®.

Perception Differences of Successful versus Unsuccessful Students (RQ #3)

Averages of post survey Likert responses were determined for successful and unsuccessful groups and are shown in Table 4-2; many differences are apparent. Medians could have been used to equal effect. To test whether the differences in perception were statistically significant, and because of the small sample sizes of successful (N=7) and unsuccessful (N=16) groups, the categorical data type, and non-normal distribution of responses, the decision was made to use the Mann-Whitney U test for this analysis (Huck, 2008). A summary of the statistical outcomes appears in Table 4.3. The Mann-Whitney U test was conducted on the raw data of the two groups and flagged differences to Prompts #8, #14, #27, and #30 as statistically significant. The Mann-Whitney U test outcome for Prompt #8 was ($U = 91$, $p = 0.0209$). Prompt #8 was, “I cannot learn physics if the teacher does not explain things well in class.” Prompt #14 was, “Understanding what I read is a problem for me” ($U = 89.5$, $p = 0.0278$). Prompt #27 was, “I prefer traditional lecture with a weekly lab compared to the self-paced VOLO work” ($U = 90.5$, $p = 0.0232$). Prompt #30 was, “I am satisfied with my grade for this unit” ($U = 15.5$, $p = 0.0076$). The null hypothesis was that the two groups had identical frequency distributions across the five possible Likert ratings. The null hypothesis was rejected because the means were significantly different between the two groups ($\alpha = 0.05$).

Notable differences were observed between successful and unsuccessful groups in the areas of SDL readiness, problem-solving ability, and alignment with expert thinking about physics. Successful students, without exception, scored higher in questions pertaining to SDL readiness and unsuccessful students expressed greater need for teacher direction (consider Prompts # 7, 8, 10-16, 27, 31, and 32). Successful students accepted responsibility for their own learning more than unsuccessful students (#12, 4.0 vs. 3.4) and expressed a preference for a self-paced VOLO learning environment whereas unsuccessful students were neutral (#27, 1.7 vs. 3.0). Successful students expressed moderate success in developing a learning strategy for the unit but unsuccessful students were less sure (#32, 3.1 vs. 2.2). Unsuccessful students strongly believed that they could not learn physics if the teacher did not explain things well in class whereas successful students felt that way a little more than half the time; this was a significant statistical difference (#8, 3.4 vs. 4.2; $U = 91$, $p = 0.0209$). Successful students expressed greater initiative and self-efficacy in their statement, "If I experience a difficulty in studying physics, I try to figure it out on my own" (#16, 3.4 vs. 2.0). To their credit, unsuccessful students said it was helpful for them to work many problems when learning physics (#3, 3.3 vs. 3.7). The groups were alike in expressing an awareness of whether they were learning something well or not (#13, 4.6 vs. 4.1); this survey prompt drew the single strongest response overall from the successful group. The groups were also alike in saying difficult study didn't bother them if they were interested in something (#11, 4.0 vs. 3.4). A cause of concern for these unsuccessful honors students was the statistically significant difference regarding unsuccessful students having difficulty understanding what they read, which links literacy to readiness (#14, 2.0 vs. 2.9, U = 89.5, p = 0.0278).

Notable differences were evident between successful and unsuccessful students in the area of physics problem solving and alignment with expert views about physics (Prompts # 1-7, 17-20, 22-25). Successful students were more able to operate at the conceptual level rather than the operational level. Successful students said that more than half the time they would thoroughly analyze a few problems in detail (# 24, 3.4 vs. 3.1) and the derivation of equations (#23, 2.7 vs. 3.1) to better understand physics. Successful students were more likely to approximate answers and assess their reasonableness (#2, 4.3 vs. 3.6). Successful students felt there was usually more than one approach to solving a physics problem (#18, 2.0 vs. 3.1). Unsuccessful students relied more heavily on equations than concepts (#25, 3.0 vs. 2.4) and felt they needed more problem-solving practice (#3, 3.3 vs. 3.7). Unsuccessful students strongly believed the teacher must show them sample problems like those on the test (#7, 3.7 vs. 4.3); this prompt elicited the single strongest response from the unsuccessful pool but was not statistically significant (U = 82.5, p = 0.0819). Successful students derived more enjoyment from problem solving (#22, 3.0 vs. 2.0). Both groups showed moderately strong need for collaborative learning (#17, 3.9 vs. 4.0).

Successful and unsuccessful students were similar in their views about tutors (see Table 4-4). The average Likert scores for accessibility and quality of the support provided by the expert tutor was (3.5 vs. 3.3 for successful vs. unsuccessful), peer tutor was (3.6 vs. 3.4), and computer tutor (masteringphysics®) was (3.3 vs. 2.6). In the free-response section, students stated that accessibility was an advantage of peer tutors and quality was an advantage of the expert tutor.

The post survey asked students, “If you had a choice of two tools or resources to use to learn physics, what would you pick and why?” Responses by successful and unsuccessful students are compared in Table 4-5 and appear similar. For both groups the number one preferred resource was masteringphysics® (50% of successful students chose and 60% of unsuccessful students chose). Students stated masteringphysics® was valuable because it “makes you practice concepts” and “forces me to learn to figure out what I did wrong so I can keep trying to get the right answer.” Both groups chose instructor support as their second favorite resource (50% vs. 27%); however, unsuccessful students also chose physicsclassroom.com as equally important (27%). Successful students also valued their textbook (34%).

The final section of the survey asked students for feedback on the self-directed mastery learning environment. The prompt was, “Comment on the mastery learning approach, which includes frequent tests with feedback from instructor and peers, followed by taking corrective actions before retesting. Do you learn more in this approach than in traditional courses?” Overall, 19 students were positive to enthusiastic about LFM, two were neutral, and three were negative. Splitting responses between successful and unsuccessful groups, 86% of successful students were positive and 76% of unsuccessful students were positive. One successful student was neutral. All negative opinions about the self-directed mastery learning environment fell within the unsuccessful group. The most commonly stated reason for preferring LFM over traditional instruction was the retaking of tests because this gave the students a chance to really learn concepts. Some selected successful student comments include: “Yes I learn more - I like this style and feedback on retaking my tests really helps”; “I like the mastery learning approach because you have to keep practicing until you understand the concept”; and “It’s more hands-on and I have to actually work to learn.” One final comment from a successful student:

> I love having all the different resources. Having the book, masteringphysics®, PhET, and other resources reinforces what I have already learned. I usually learn something different in every resource. In the traditional classroom you move on more quickly, but with mastery learning you can retake the tests until you completely understand every problem, if you want. Therefore I learn more from mastery learning.

Of the neutral comments, one unsuccessful student said “I feel like I learn the same amount, it is just performed using a different method. I would like a little more time in the classroom where the teacher could explain concepts.” Of the negative comments, one unsuccessful student wrote “Mastery learning approach = frustrating; frequent tests = frustrating.” Another criticism was, “I do not like the approach. The approach may have been more effective if the students knew how to work the problems.” One final criticism was “I like being able to retake, but I always feel like I’m scrambling before every test.”

Summary

In conclusion, the two physics classes were split into successful and unsuccessful groups according to whether the students cleared the unit test in four tries, and seven of 24 students accomplished this. Both groups of students were positive about the self-directed mastery learning environment (86% of successful students were positive and 76% of unsuccessful students were positive). The main reason given for preferring the self-directed mastery learning environment over traditional instruction was that formative testing helped the student learn from their mistakes. The favorite resource of all students was the computer tutor, masteringphysics®, followed by tutoring with the instructor. Students allocated twice the time to peers than anything else. Successful students invested an average of 25% more time than unsuccessful students in SDL activities, particularly in retesting, tutoring with the instructor, and doing homework. Many notable differences between the perceptions of successful and unsuccessful students were indicated by post-survey results in the areas of SDL readiness, problem-solving approaches, and alignment with expert views about physics. These comparisons between successful and unsuccessful students will be more thoroughly discussed in Chapter 5.

Table 4-1. VOLO activities selected by percentage, and average educational value and enjoyment scores.

% of students selecting this activity	VOLO Activity	Average Educational Value (1=low, 5=high)	Average Enjoyment Score (1=low, 5=high)
100%	Masteringphysics®	2.8	2.8
100%	PBB Lab	2.5	2.5
100%	PhET Energy Skate Park	2.5	2.5
58%	KE-PE Quiz	3.4	3.1
25%	Outline chapter	3.4	3.0
4%	PhET Spring Virtual Lab	4.5	3.5
50%	Roller Coaster Tycoon® virtual roller coaster	2.9	4.3
17%	Extra pendulum experiment	4.2	4.2

Table 4-2. Comparison of post survey average Likert responses of successful versus unsuccessful students (N=24).

Question #	Successful Average Likert Score	Unsuccessful Average Likert Score	Question/Prompt
# 1	2.0	2.4	A significant problem in learning physics is being able to memorize all the information I need to know.
# 2	4.3	3.6	When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.
# 3	3.3	3.7	It is useful for me to do lots and lots of problems when learning physics.
# 4	3.1	2.0	I think about the physics I experience in everyday life.
# 5	2.3	2.7	Knowledge in physics consists of many disconnected topics.
# 6	4.0	2.9	When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.
# 7	3.7	4.3	To do well in this physics course, I need to see sample problems like those on the tests.
# 8	3.4	4.2	I cannot learn physics if the teacher does not explain things well in class.
# 9	3.7	3.1	I am developing general problem-solving techniques in this course.
# 10	2.9	2.6	In a learning experience, I prefer to take part in deciding what will be learned and how rather than having the teacher tell me what to do.
# 11	3.9	3.6	Difficult study doesn't bother me if I'm interested in something.
# 12	4.0	3.4	No one but me is truly responsible for what I learn.
# 13	4.6	4.1	I can tell whether I'm learning something well or not.
# 14	2.0	2.9	Understanding what I read is a problem for me.
# 15	3.1	2.6	If I discover a need for information that I don't have, I know where to go to get it.
# 16	3.4	2.0	If I experience a difficulty while studying physics, I try to figure it out on my own.
# 17	3.9	4.0	To understand physics I discuss it with friends and other students.
# 18	2.0	3.1	There is usually only one correct approach to solving a physics problem.
# 19	2.3	2.5	I do not expect physics equations to help my understanding of the ideas; equations are for doing calculations.

Table 4-2. Continued

Question #	Successful Average Likert Score	Unsuccessful Average Likert Score	Question/Prompt
# 20	3.1	2.4	The first thing I do when solving a physics problem is make a drawing to represent it.
# 21	3.9	3.1	I am not satisfied until I understand why something works the way it does.
# 22	3.0	2.0	I enjoy solving physics problems.
# 23	2.7	3.1	I do not invest time understanding the derivations of equations.
# 24	3.4	3.1	I have found carefully analyzing only a few problems in detail is a good way for me to learn physics.
# 25	3.0	2.4	It is possible to explain physics ideas without mathematical formulas.
# 26	1.9	1.8	I prefer to learn from our Glencoe textbook rather than Internet resources.
# 27	1.7	3.0	I prefer traditional lecture with a weekly lab compared to the self-paced VOLO work.
# 28	2.7	2.7	I invested significant hours outside of class because I did not have sufficient time during class to learn this material.
# 29	3.6	2.4	I have mastered the key ideas about conservation of energy.
# 30	4.0	2.2	I am satisfied with my grade for this unit.
# 31	4.1	3.6	Retaking the unit test helped me figure out my weak spots and focused my learning.
# 32	3.1	2.2	I developed a learning strategy that worked for me for this unit.
# 33	3.3	2.6	Masteringphysics® was very helpful to my learning process.
# 34	2.6	2.4	PhET Energy Skate Park was very useful to my learning process.
# 35	2.9	2.3	The Pendulum-Box Bash experiment was very useful to my learning process.
# 36	3.6	3.2	This unit had the right balance of whole-class, small-group, and individual learning activities.
# 37	3.6	3.1	I had all the support I needed – whether from the teacher, peers, or course resources – to learn this material.
# 38	3.4	3.4	Some class periods I accomplished very little.
# 39	4.0	3.6	I have a very productive team in this course.
# 40	2.3	2.3	I had a plan for what I wanted to accomplish each day BEFORE I entered the physics classroom.

Table 4-3. Mann-Whitney U test indicated post survey Likert responses were statistically different between successful and unsuccessful groups (α = 0.05)

Individual survey questions indicated to have statistically different responses between successful/unsuccessful groups	#8 (U = 91, p = 0.0209) #14 (U = 89.5, p = 0.0278) #27 (U = 90.5, p = 0.0232) #30 (U = 15.5, p = 0.0076)
Advantages of statistical method	Non-parametric method applicable to ordinal data type with non-normal distribution and small sample sizes. Operates by comparing sum-of-ranks between two groups and determines likelihood (p) of the differences (Huck, 2008).
Limitations of statistical method	None (Huck, 2008).
H_o	REJECTED: The average ranks of the successful and unsuccessful groups were the same.

Table 4-4. Likert ratings by successful and unsuccessful students of accessibility and quality of three tutor supports

Tutor Type	Successful	Unsuccessful
Expert	3.5	3.3
Peer	3.6	3.4
Computer	3.3	2.6

Table 4-5. Comparison of successful vs. unsuccessful group responses to the post survey question, “If you had a choice of two tools or resources to use to learn physics, what would you pick and why?”

Group	% that selected	Tool/Resource
SUCCESSFUL (N=7)	50	Masteringphysics®
	50	Instructor
	34	Textbook
	17	Physicsclassroom.com; peers; lab; internet
UNSUCCESSFUL (N=16)	60	Masteringphysics®
	27	Instructor
	27	Physicsclassroom.com
	14	Textbook; internet
	7	Rube Goldberg; practice quizzes; lab; retaking tests; peers

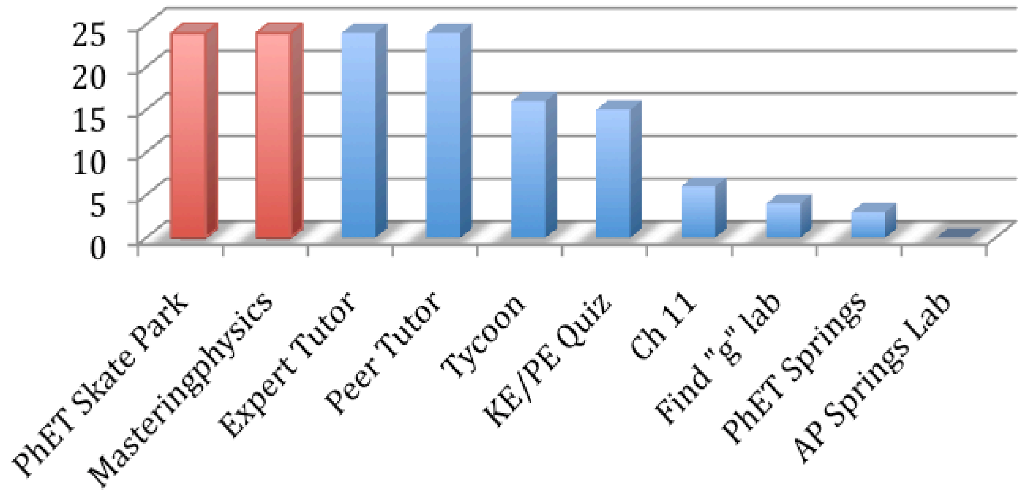

Figure 4-1. The tally of SDL activity choices indicates all students completed the required activities and all used expert and peer tutors.

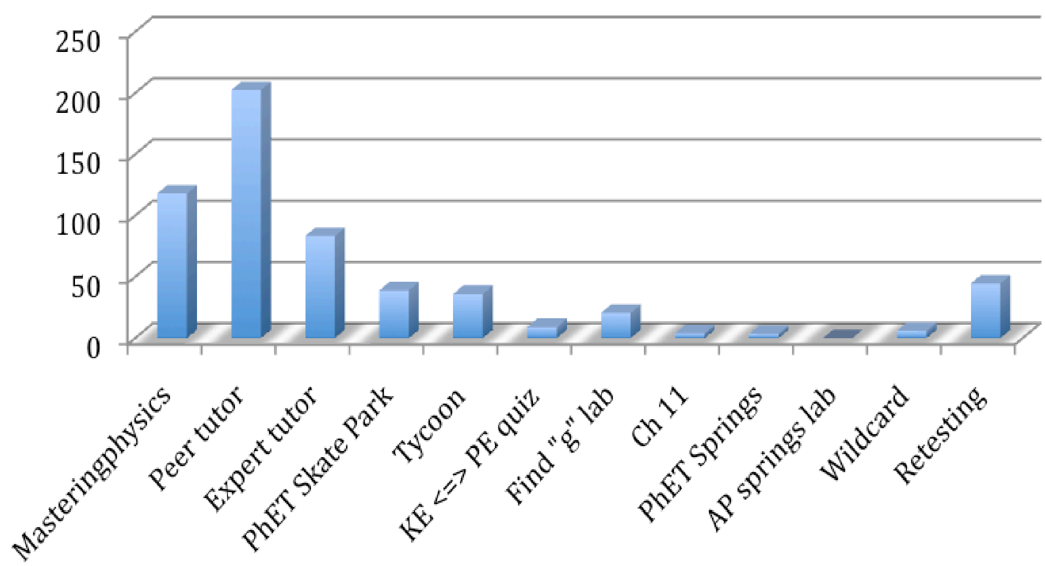

Figure 4-2. Average minutes invested per SDL activity per student. Time data based on Time Tickets and masteringphysics® time logs.

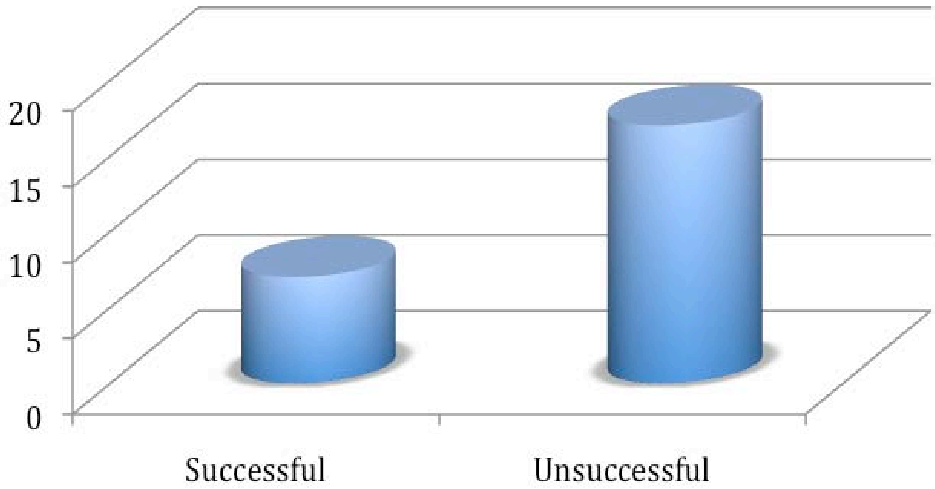

Figure 4-3. The number of students who cleared the unit test in four tries is shown. Seven students cleared the unit test within four tries and 17 students did not.

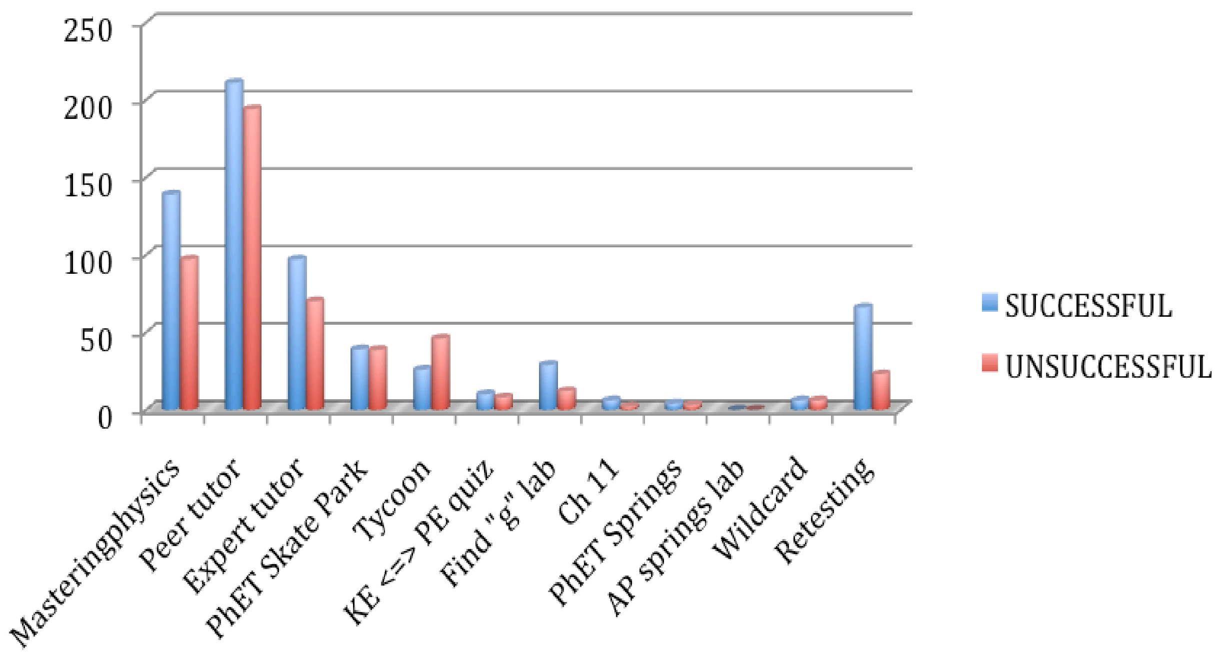

Figure 4-4. SDL activities evaluated based on minutes invested by successful and unsuccessful groups. Overall, successful students spent 25% more time on their activities than unsuccessful students did.

CHAPTER 5
FINDINGS, DISCUSSION, CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORK

This chapter consists of six sections: Overview, Limitations, Findings, Discussion, Conclusions, and Recommendations and Future Work. The Overview and Limitations sections provide a condensed description of the design and implementation of the study in the light of its limitations and literature base. This section is followed by the Findings section, in which the findings of Chapter 4 are summarized. The Discussion section ties the literature, research questions, and findings together, and Conclusions are drawn. This is followed by the Recommendations and Future Research section, which provides practical recommendations based on this research as well as ideas for future research efforts with a rationale for why these research areas are important.

Overview of the Study

This four-week study captured data for one learning unit completed by all students in two honors physics classrooms (N=24) in February 2011. The topic of the four-week learning unit was conservation of energy. The major concepts presented were:

- Force, work, power, kinetic energy, and potential energy are related.
- The Law of Conservation of Energy relates different energy forms and some forms of energy, such as friction, are hard to determine.
- Pendulums and springs alternate between potential and kinetic energy with virtually no energy losses and provide good models for the study of conservation of energy.
- Roller coasters provide a real-world application of conservation of energy because they alternate between potential and kinetic energy, but some energy is lost due to friction.
- It is nearly impossible to use conservation of energy laws to resolve inelastic collision problems; however, conservation of momentum laws may be used.

No training, logistical, nor technological challenges occurred. Whole-class and self-directed learning proceeded as envisioned and the VOLO activities were robust. Google® Apps provided an infrastructure for the physics course and no technical issues occurred. Students' personal web pages enabled dynamic workflow management for the instructor. Google® Docs enabled collaborative development of lab reports.

Two significant whole-class activities were important to concept development but were not included in the data analysis because the focus of this study was self-directed learning. The two activities were the Rube Goldberg project and the Pendulum Box Bash Lab (PBB Lab). The Rube Goldberg project was a competition between the two physics classes and functioned as a whole-class activity. The two teams greatly exceeded expectations for this project and it ran longer than expected (consumed a week). It is noteworthy that the requirements were to fold a piece of paper into quarters using at least five energy conversions. Team 1 used 65 energy conversions and Team 2 used 50 energy conversions. The competition became a well-attended event and a video of it was featured on the school's morning announcements. The Rube Goldberg project received very favorable unsolicited comments in the post survey, such as "Rube Goldberg – 5 - hands-on learning, loved it!" and "The Rube Goldberg helped me to visualize physics."

The second whole-class activity that was important for conceptual development but not included in the capstone analysis was the Pendulum Box Bash Lab (PBB Lab), adopted from the work of Zou (2000), which involved 1.5 days of whole-class hands-on lab and discussion. The core ideas presented in the lab were the conditions under which conservation of energy laws would NOT apply in contrast to conservation of momentum laws that DO apply. Zou (2000) created test questions that tracked the same concept in different “packaging” and he analyzed how Ohio State University physics students applied their laboratory experience to new situations. For this study, after three tries 82% of the students answered the PBB Lab questions correctly. Post survey responses gave the PBB Lab an educational value rating of 2.5 out of 5 on the Likert scale, which was one of the lowest scores (the only lower score being reading the Glencoe© textbook, which scored 1.8 out of 5). This score translates to students feeling the PBB Lab was not very useful to their learning process, whereas the instructor viewed the embedded concept to be very important.

The first research question pursued in this capstone study was “What SDL activities did honors physics students choose in their self-directed mastery learning environment?” The SDL-LFM instructional strategy was tied to physics concept development via the second research question: “How many students achieved concept mastery when SDL activities were infused into the honors physics classroom for a given time period, and how did they spend their time?” Finally, perception differences between successful and unsuccessful students were evaluated through the third research question: “Did successful and unsuccessful students perceive the self-directed mastery learning environment differently?”

Self-direction was a focus because assuming responsibility for one’s own learning is deemed an important college and career skill (Partnership for 21st-century skills, 2006). Mastery learning was pursued because it is a time-tested method of achieving learning gains in the 0.5-1-sigma range, improving attitudes towards school, and personalizing the learning experience (Bloom, 1968, 1984; Guskey, 2007, 2010;

Hymen, 2002; Kulik, Kulik, & Bangert-Drowns, 1990). SDL and LFM are interrelated. LFM facilitates SDL and concept development through feedback and prescriptive learning, and SDL facilitates LFM by freeing the instructor to spend more one-to-one time with students.

Mastery learning involves one-to-one tutoring with the student (Bloom, 1968; Keller, 1968). To free the instructor for more one-to-one time with students, VOLOs were developed and peer and computer tutors were added. During this time with students, the instructor used formative tests as the foundation for providing targeted feedback to the student, as well as making suggestions for corrective action. The student had up to four tries to pass the unit test and his/her best grade was retained. Frequent formative tests with feedback and correctives are the hallmark of mastery learning (Bloom, 1968, 1984; Keller, 1968). Self-direction was accomplished through the VOLO structure, which provided a selection of learning activities that were tracked and analyzed. It was thought that the choice of learning activities would accommodate differences in learning styles, interests, and readiness as well as create a sense of ownership (Guglielmino, 2000; Tomlinson, 2003). The learning activity choices of successful and unsuccessful students were compared (success was defined as scoring at least an 80% on the unit test within four tries.)

Self-directed learning environments require sufficient levels of support to be effective (Breslow, 2004; Chang, 2008; Hendry, 2009; Kirschner, 2006; Mayer, 2004; Taylor, 1995). Three types of support were available to students – expert, peer, and computer tutors. The emphasis on tutors was consistent with the mastery learning methodology (Bloom, 1968, 1984). Students' use of support structures was tracked by minutes invested, and their opinions about the availability and quality of support were assessed through the post survey. The time investment of successful students with tutors was compared to the time investment of unsuccessful students. By comparing the time allocation choice data of successful students and unsuccessful students, some conclusions were drawn about SDL effectiveness in general and particular SDL activities which yielded learning gains.

Through a post survey, perception differences about SDL readiness, basic problem solving and development of expert thinking about physics, and opinions about the self-directed mastery learning environment were explored between successful and unsuccessful groups. Coupling the perception data with the time allocation data allowed a preliminary profile to emerge of a self-directed learner on the pathway to becoming an expert in physics.

Limitations

All data was collected as planned; however, Time Tickets were crucial to the analysis and their execution was somewhat flawed. Specifically, every student did not fill out a Time Ticket every day, because perhaps they were not near a computer at the close of class. Hence students sometimes filled out several Time Tickets retroactively, and this reduced the reliability of this instrument with the exception of the computer tutor times that were accurately known. Also, three students filled out so few Time Tickets that they were not part of the time studies. Another limitation of the study was the inherent bias of the researcher due to the research being conducted within her classroom, and the fact that this was the second year that the instructor had taught these same students.

Findings

RQ #1 Findings – SDL Activities Chosen

VOLO tallies determined that 96% of students completed at least four VOLO activities for the unit, and the most popular elective VOLO activity was Roller Coaster Tycoon®, followed by the online KE ⇔ PE quiz (Figures 4-1 & 4-2). On the basis of minutes invested in an SDL activity, peer tutoring consumed double the time of any other option (203 minutes). Masteringphysics® was a distant second in time consumed (118 minutes) followed by instructor support (84 minutes). Thus, the three support structures garnered the greatest time investment of the students. Retesting, PhET Skate Park and Roller Coaster Tycoon® each consumed approximately 40 minutes per student. Interpretation of this data must be tempered by the inconsistency with which students submitted their Time Tickets. Students allocated more time to required activities, whereas electives were often chosen based on the "quick-and-easy," or "I-thought-it –would-be-fun" mindset, according to post survey responses. A clear cutoff was evident when one considers the minutes invested in electives. Roller Coaster Tycoon® was the only elective that garnered much time investment from the students.

The post survey comments conveyed the advantage of the peer tutor was availability whereas the advantage of the expert tutor was quality of feedback. For instance, one student wrote about the peer tutor, "[Peers] are good at giving answers but not too great at explaining. I usually let the teacher explain things to me. She has a very thorough knowledge of the material herself, so this helps." Another student commented, "My peers are readily accessible… but they do not know everything," which balanced the student who said, "I wouldn't fully understand the concept when [the teacher] was finished explaining it. My peers were probably more helpful than the teacher. I would say they were able to explain things better." Still another commented, "My peers were very accessible; we worked together in class and worked outside of class through Skype® several times. It proved very effective. We were able to support each other and talk through difficult concepts." Regarding the expert tutor, one student said, " I talked to her most of the time but sometimes she's a little busy and we can't get her attention." The computer tutor was cited frequently as a useful tool for learning physics: "I like the way the information is presented and the hints work you through a problem instead of giving you the answer right away."

In summary, the data supporting RQ #1 revealed students were skilled in attaining high VOLO grades, all completed the required VOLO activities, and all accessed the three types of support. Elective activity choices generally reverted to those that were quick, easy, and fun. The greatest time investment of students was in peer support, which was double the time invested in masteringphysics®, the next most time-consuming activity.

RQ #2 Findings – Relationship between SDL Activities and Concept Mastery

At the close of the unit, only seven students had cleared the unit test with at least an 80% given four tries and the average unit test score was a very poor 57%. The instructor did not consider the series of tests difficult (Appendix C shows a sample test). Care was taken to align test questions with masteringphysics® (11 of 34 test questions came directly from this source), the PBB Lab, PhET energy park, the pendulum experiment, and the textbook. The seven students who cleared the test were separated into the "successful" group and their time allocation choices and perceptions were evaluated separately from the unsuccessful students. When time investment in SDL activities of successful and unsuccessful groups was compared, it was evident that successful students consistently invested more time in every activity, particularly their masteringphysics® homework problem set (139 minutes vs. 97 minutes) and tutoring with the instructor (97 minutes vs. 70 minutes), for an overall average of 25% more time invested than their unsuccessful counterparts with the sole exception of the Roller Coaster Tycoon® activity. Roller Coaster Tycoon® was the fourth most significant time investment of unsuccessful students (26 minutes vs. 46 minutes) and deemed the “most enjoyable” in the post survey. While unsuccessful students built virtual roller coasters with Tycoon®, successful students invested time learning from their mistakes on formative tests (retesting was the fourth most significant time investment of successful students - 66 minutes vs. 23 minutes). Both groups invested the largest number of minutes in collaborative learning (211 minutes vs. 194 minutes).

To summarize, the data supporting RQ#2 revealed that successful students invested 25% more time in their learning activities than did unsuccessful students and triple the time in formative testing. In rank order, successful students prioritized their time as follows: peer tutor, computer tutor, expert tutor, retesting, PhET Skate Park, find “g” lab, Tycoon, KE⇔PE quiz. Unsuccessful students prioritized their time as follows: peer tutor, computer tutor, expert tutor, Tycoon, PhET Skate Park, retesting, find “g” lab, KE⇔PE quiz.

RQ #3 Findings – Differences in Perception between Successful and Unsuccessful Students

Patterns were sought in the areas of SDL readiness, basic problem solving and development of expert thinking about physics, and perceptions of the self-directed mastery learning environment. Due to the small sample size (N=24), a factor analysis was not conducted for the post survey. Throughout this section, questions will be referred to as “#12” for Question #12 (see Table 4-2) and Likert scores will be shown as (5.0 vs. 4.3) for (mean of successful Likert ratings vs. mean of unsuccessful Likert ratings). The Likert scale ranged from 1 = “I never feel this way” to 5 = “There are very few times when I don’t feel this way.” When a question had a statistically significant outcome as determined by the Mann-Whitney U Test ($\alpha = 0.05$), this is noted in the narrative.

SDL readiness. Considering the prompts related to SDL readiness, one emergent theme was that unsuccessful students expected more direct instruction from the instructor. Unsuccessful students felt it was essential for the instructor to explain things well in class and to see sample problems exactly like those on the test. One of the students who gave a negative vote to LFM wrote, “I prefer for the teacher to teach us everything we need to know.” Unsuccessful students were less confident to resolve problems on their own and less convinced of their responsibility to manage their own learning. They were markedly disappointed in their inability to develop a successful learning strategy for the unit. Successful students, in contrast, embraced the freedom provided by the SDL framework and were pleased with their learning outcomes. They felt they were responsible to manage their own learning so the instructor was less essential. They were more confident of their literacy skills and knew where to go to get information.

Basic problem-solving strategies and development of expert thinking about physics. Development of expert thinking requires time and successful construction of knowledge (Bransford, 2000). Ultimately, the expert becomes capable of pattern recognition and categorization of problems, which guides limited cognitive functions towards problem resolution (Bransford, 2000; Gagne, 1988; Larkin, 1980). Novices, in contrast, remain tangled in the details, consuming their limited cognitive capacity with minutia, thereby making it difficult to elevate their thinking to solve the problem (Bransford, 2000; Larkin, 1980). Physics experts often use drawings to compose their thinking and are more contemplative in using equations than a novice, operating at a more conceptual level (Halloun, 2001; Halloun & Hestenes, 1998).

Notable differences emerged between successful and unsuccessful students in their perceptions about ways to solve physics problems. Post survey results indicated successful students showed evidence of expert thinking about physics whereas the unsuccessful students were lagging (Halloun, 2001; Halloun & Hestenes, 1998). For instance, successful students gave a strong response to post survey Prompt #6, “When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented” (#6, 4.0 vs. 2.9). This prompt related to the pattern formation that is characteristic of experts. On the flip side, unsuccessful students were more likely NOT to see patterns, as evidenced by their somewhat elevated response to the prompt, “Knowledge in physics consists of many disconnected topics” (#5, 2.3 vs. 2.7). Successful students were more likely to relate physics to their everyday world (#4, 3.1 vs. 2.0), which was again a testament to their identification of patterns and themes.

Perceptions of the self-directed mastery learning environment. The average Likert scores for successful and unsuccessful groups recorded in Table 4-2 for questions pertaining to the learning environment (Prompts # 26–40) appear similar with two notable exceptions. Prompt #27 contrasted opinions between traditional to SDL, specifically, “I prefer traditional lecture with weekly lab compared to the self-paced VOLO work.” The average score of successful students was 1.7 (corresponding to “I almost never feel this way”) and the average score of unsuccessful students was 3.0 (corresponding to “I feel this way half the time.”) This was a statistically significant result ($U = 90.5$, $p = 0.0232$). Unsuccessful students did not feel they mastered the key ideas of the unit whereas successful students did (#29, 3.6 vs. 2.4). Unsuccessful students were highly dissatisfied with their grades for the unit, in contrast to successful students (#30, 4.0 vs. 2.2); this was a very significant outcome ($U = 15.5$; $p = 0.0076$).

Certain prompts elicited similar responses from successful and unsuccessful students. Both groups agreed they would rather use the Internet to learn than the textbook (#26, 1.9 vs. 1.8); they appreciated the opportunity to retake tests to focus their learning (#31, 4.1 vs. 3.6); they felt they had adequate support from teacher, peers and course resources (#37, 3.4 vs. 3.1); and they felt that the unit had the right blend of whole-class, small-group, and individual learning activities (#36, 3.6 vs. 3.2).

Free-response section. Three specific areas were probed in the free-response section of the survey. The first profiled students’ opinions about the accessibility and quality of tutors, and this has already been presented in Table 4-4. Both groups were similar in their ratings of the three supports (an approximate score of 3). The second area probed was students’ favorite two resources to learn physics. As shown in Table 4-5, both groups valued masteringphysics® most highly (50% vs. 60% mentioned), followed by instructor support (50% vs. 27% mentioned). It is relevant to contrast these responses with the time allocation data, which emphasized that the number one resource used by students was peer support, accessed twice as frequently as any other resource. Perhaps time allocated to peer support wasn't always focused on learning physics, but time devoted to masteringphysics® clearly was.

The final free-response section of the survey provided students with an opportunity to review the mastery learning approach. Some 86% of successful students were positive about LFM, and 76% of unsuccessful students were positive. One successful student was neutral. All negative opinions about the self-directed mastery learning environment fell within the unsuccessful group. The most commonly stated reason for preferring LFM over traditional instruction was the retaking of tests because this gave the students a chance to really learn concepts.

Discussion

The overall class atmosphere was positive, collaborative, and industrious. Only once in four weeks did the instructor need to speak to a student to get to work. The VOLO structure worked well as an SDL framework with clear rubrics and due dates (Guglielmino, 2000). Students clearly understood they needed to complete five VOLO tasks to receive the full grade, and they usually chose a partner(s) to complete the VOLO task. Teachers can create supportive environments in which collaboration is frequent and socio-cognitive construction of knowledge is possible (Buschman, 2003). Good instructional design encourages active learning. "Learning is not a spectator sport.... [Students] must talk about what they are learning, write about it, relate it to past experiences and apply it to their daily lives. They must make what they learn part of themselves" (Chickering & Gamson, p. 66). Mastery learning fosters a collaborative learning environment because it is based on expert and peer interaction and dispels with competition for high grades (Bloom, 1978). The mastery learning environment appeared a nurturing space for students to receive feedback and learn from their mistakes in their efforts to achieve concept mastery; however, future efforts must drive towards greater learning outcomes in addition to positive perceptions.

The most significant time investment, by a 2:1 margin, was time invested with peer tutors. It was unclear whether peer support always translated to physics help and dialog or whether some of that time was social (post-survey results attributed less quality to peer support than expert support). Merrill & Gilbert (2008) found the best collaborative learning was problem-centered. "Learning is promoted when learners are engaged in a task-centered instructional strategy involving a progression of whole real-world tasks" (Merrill & Gilbert, 2008, p. 200). The VOLO activities were clearly structured as to task but Merrill and Gilbert (2008) suggest students may have benefitted from more guidance as to how they should collaborate. For instance, Crouch and Mazur's (2001) concept tests in university physics courses require students to convince their peers that they have the right solution to a problem. Merrill and Gilbert (2008) clarify the changing role of peers through the instructional process: Peer-sharing in the activation phase, peer-demonstration in the demonstration phase, peer-collaboration in the application phase, and peer-critique in the integration phase. This final phase of peer-critique "requires deeper processing for students to make their intent clear for collaborators" (Merrill & Gilbert, 2001, p. 202). Specification of the nature of peer interactions may be an enhancement for future SDL course design.

In general, students spent more time in required activities but enjoyed them less (# 41). The majority of students chose learning activities because they were "quick and easy" and "fun," but then they could not pass the test. The successful students might have chosen these same activities, but extracted learning in the process of doing them. For instance, one successful student commented,

> I always read at least part of a chapter, but usually all of it, because the book is easy to understand and provides a good introductory understanding of the concept. I built the [virtual] roller coaster because it was quick and easy to relate to after the Islands of Adventure trip. I took the KE⇔PE quiz because working problems reinforces the concepts that I have already learned and checks my understanding.

Successful students expressed metacognitive intention behind their choices, sometimes choosing a sixth activity to supplement their learning. Unsuccessful students, in contrast, seemed in a rush to complete their VOLO, unaware that this was their opportunity to learn the concepts. Successful students expressed the need to practice and apply concepts to master them.

Two issues with the VOLO structure were noted: 1) the selection of VOLO activities was critical and 2) some students hurried through a task to “check it off the list,” with little regard to the activity’s learning potential. The first issue naturally resolves over time as the instructor gains feedback about the learning content and student uptake of various activities. For instance, the capstone work clearly indicated the value of masteringphysics® for this unit. As far as the second issue, the only way to change student’s behavior regarding rushing through SDL activities is to reinforce that they are responsible for their own learning. Idros (2010) and Taylor (1995) address this challenge and state that one of the most important tasks of the SDL instructor is to raise student awareness of their responsibility to manage their own learning. Breslow (2004, 2007) and Gibbons (2002) point out that this shift in responsibility from the teacher to the student can raise discomfort for both parties. Students, accustomed to passively sitting and receiving, are forced to manage their own learning, which Guglielmino (2000) identifies as an important career survival skill. Instructors experience a loss of control that causes them discomfort (Gibbons, 2002). Herbal-Eisenman & Breyfogle (2005) and (Pape, 2000) indicate that the transition in ownership can be smoothed through constructive discourse and modeling problem solving and Learning to Learn strategies.

The majority of students were positive about the self-directed mastery learning environment (#45, 86% vs. 76%). Research indicates several factors that were embedded in the capstone study that might have contributed to a positive learning climate: a choice of learning activity (Knowles, 1975; Taylor, 1995; Tomlinson, 2003), peer interaction (Mazur, 2007; Merrill, 2008), personalized attention (Bloom, 1968, 1984; Chickering & Gamson, 1991), a lack of competition for high grades (Bloom, 1978; Chickering & Gamson, 1991), adequate support (Kirschner, 2006), sufficient time to master concepts and complete the work (Bloom, 1968, 1984; Cavanaugh, 2009), a chance to learn from mistakes (Bloom, 1968, 1984), effective technology applications (Bates & Poole, 2003; Jonassen, 2003; Koohang, 2009), and hands-on activities (Breslow, 2007; McDermott, 2001, 2002). The Google® Apps infrastructure worked flawlessly and supported the SDL-LFM learning environment.

Regarding learning outcomes, the final average unit test score was very poor (57%) for the unit and only seven of 24 students had cleared the test. This was a disheartening outcome considering the effort made to create and manage the capstone course structure. A surprising epilogue to the capstone story followed the presentation of these results to students after which they were given five days to prepare for an additional test. Everything changed. A remarkable 51% gain in test scores occurred,15 students cleared the test, and the class average jumped to 79% (Figure 5.1; gain was calculated as [(Recent Score – Previous Score) / (100 – Previous Score)]). Was this a grand example of procrastination? Four possible interpretations were (1) Yes, students procrastinated; (2) Students needed clearer feedback to determine what they needed to do to reach success; (3) SDL was not modus operandi and students still needed the teacher to drive their activities; and (4) Not enough time was allocated to the learning unit. The radical shift in test performance lent credence to Chickering and Gamson’s (1991, p. 66) view that, "No feedback can occur without assessment. But assessment without timely feedback contributes little to learning." Feedback is vital to the learning process. Much of the current literature on discourse and metacognition is built on the principle that feedback fuels the learning process (Cobb, Wood & Yackel, 1993; Herbal-Eisenman & Breyfogle, 2005; Verschaffel,1999). Mandernach (2009) says the most important factor stimulating critical thinking is instructor involvement. Bloom (1968) describes the expert tutor as a listener, who asks questions and represents concepts in a different way, trying to break through the learner's misconceptions or assist them in building schemas. "In other words, to decrease variation in results, the teacher must increase variation in their teaching" (Guskey, 2007, p.16). Guskey (2007) emphasizes early intervention yields the greatest gains: "The time used for correctives and enrichments in early units yields powerful benefits that later will make things easier" (Guskey, 2007, p. 19). SDL does not translate to a lessened need for feedback but as Aubdullah (2001) and Hogg (2008) indicate is often associated with increased collaboration between the student, teacher, and peers. Timely and assessment-based feedback should be an important component of future course designs.

The third explanation for the radical post-study turnaround in test scores, specifically that students were not equipped or prepared for SDL and were accustomed to teacher direction, has merit. A gradual shift from teacher direction to student direction has been advocated by several authors (Bolhuis, 2003; Gibbons, 2002). Whereas the capstone study was preceded by a semester-long pilot study, SDL is a characteristic of the learner and not the instructional strategy, thus learners differ in their capacity to assume control of their learning even after a semester of practice (Bolhuis, 2003). Teaching should provide students with “constructive frictions” that require them to exercise a little more self-direction than they had in the past (Bolhuis, 2003, p. 339). Modeling is a method whereby the instructor makes the process of learning transparent for the learner and is a recommended technique for building SDL skills (Bolhuis, 2003; Verschaffel, 1999).

The fourth explanation regarding inadequate time points to the essential idea that time on task relates directly to learning (Cavanaugh, 2009; Chickering & Gamson, 1991). Time Ticket data revealed over the four-week period the average student – whether successful or unsuccessful - invested only 2-3 hours in physics homework. Focusing on allocation of class time, therefore, successful students allocated 25% more time to learning activities (633 minutes vs. 500 minutes). The emphasis on retesting may have been one of the most defining elements of success. As a percentage, retesting was the activity eliciting the greatest time difference between successful and unsuccessful students. On average, successful students invested almost triple the time in retesting than did unsuccessful students (66 minutes vs. 23 minutes). In addition, expert tutor time was often associated with correcting and reviewing for tests, and successful students spent more time with the expert tutor than unsuccessful students (97 minutes vs. 70 minutes). In the post survey, both successful and unsuccessful students acknowledged the importance of formative testing (see survey results under RQ #3, Question #31 – average Likert score of 4.1 for successful students and 3.6 for unsuccessful students), but successful students took greater advantage of it and gleaned more feedback from the instructor.

Successful students expressed greater metacognition and intention in time usage on the post survey; specifically, they targeted certain activities to provide practice with concepts and minimized time investment in less educational activities (Roller Coaster Tycoon®). One unsuccessful capstone student, whose split of minutes for expert/peer/computer tutoring time was 10/260/90, analyzed that the reason she did not do well on the unit was because she did not work example problems with the teacher, which usually helped her a lot. These results are consistent with Abar & Loken's (2010) evaluation of 205 high school students. They found highly self-regulated students (as determined from measures of metacognition, effort, efficacy, and positive attribution, among others) studied more material for a longer time than less self-regulated students. In addition, highly self-regulated students had a mastery goal orientation and used appropriate resources to attain their goals (Abar & Loken, 2010).

Did the SDL structure allow the instructor to engage in more one-to-one tutoring? A review of Time Ticket data (Figure 4-2) shows that the expert tutor spent an average of 167 minutes per student over 10 class periods (four weeks total, minus four FTF days, minus five Rube Goldberg days, minus test-taking days). This then reduces to an average of 16.7 minutes per student per day, which is not an impressive number except when one considers a typical class period, if divided by the number of students, allowed approximately 4 minutes per student. The Time Ticket data was faulty, and these impressions require further investigation; however, it appeared that students gleaned more personal time with the instructor and this concurred with the instructor's view that lecture time was converted to one-to-one interactions that were more targeted to the student's needs.

Conclusions

A profile of a self-directed secondary honors physics student emerged through this research. A successful self-directed student invested more time learning from activities rather than simply completing them, intentionally selected activities to fill in gaps of knowledge and practice concepts, actively constructed knowledge into a cognitive framework, focused on learning concepts more than rote operations, engaged in academic discourse with instructor and peers as they made repeated attempts to master content and pass the test given constructive feedback, used a wide variety of learning resources, and managed their workload to meet deadlines. Considering the interesting epilogue to the capstone story, i.e. given an extra week eight additional students cleared the unit test, one could conclude that SDL readiness was the characteristic lacking in the unsuccessful students. Perhaps their original poor test performances could be attributed to insufficient time and intention for schema development, or insufficient feedback, or both, which resulted in underdeveloped problem-solving ability. Once they were given assessment-based feedback, reviewed the material again with the instructor and prepared properly using their older tests, they were able to master the concepts. They always had the ability to master the concepts, but lacked the SDL skills and motivation to manage the learning process.

Knowles (1975) defines a self-directed learner as an individual who takes initiative, with or without the help of others, diagnoses his/her learning needs, formulates goals, identifies resources, chooses and implements appropriate learning strategies, and evaluates learning outcomes. The profile that emerged from the capstone study is consistent with the SDL definition provided by Knowles. In this study, the seven successful students differed from the 17 unsuccessful students in SDL readiness according to post survey results. In Bloom's (1968) terms, the unsuccessful students were still highly dependent upon the expert tutor, which translates to the instructor needing to modify instructional strategies to make better connections for the students. This is a teacher-led view. Unsuccessful students agreed with statements such as, "I can't understand physics if the teacher doesn't explain things well in class" (#8, 3.4 vs. 4.2), in contrast to successful students who agreed, "No one but me is truly responsible for what I learn" (#12, 4.0 vs. 3.4). Unsuccessful students preferred traditional, teacher-led instruction (#27, 1.7 vs. 3.0).

By separating successful and unsuccessful students and evaluating their behaviors and perceptions, the instructor gained a clearer perspective about how to create, support, and sustain an effective self-directed mastery learning classroom. "Effective" captures the goal of improved learning outcomes (and attitudes – not a goal of this work but often a side-product of mastery learning (Bloom, 1978)). An instructor can take steps to foster SDL skills, problem-solving ability, and expert thinking. From Bloom's perspective (1968, 1984), more time with the expert tutor, more feedback, and more correctives are recommended. Pape (2003) and Verschaffel (1999) make similar recommendations by promoting modeling with discourse, but they extend into self-direction by recommending explicit instruction in Learning to Learn strategies as well. Because students differ in their readiness, a gradual transition is recommended (Abdullah, 2001; Bolhuis, 2003; Breslow, 2003; Gibbons, 2002). This parallel instruction in content and process is the fundamental recommendation emerging from this study. Mastery learning principles coupled with modeling in self-direction appear mutually reinforcing and, when more explicitly approached, should yield dual benefits in concept mastery as well as self-efficacy.

Recommendations and Future Work

This capstone study found that parallel instruction in content and SDL skills could be important for improving learning outcomes and better equipping secondary honors physics students for college and life in general. Self-direction skills are important in a knowledge-based society and prepare students to persist, manage their time and resources, use logic to construct their knowledge, argue their views, collaborate, and hopefully, find meaning through the learning process (Partnership for 21st-century skills, 2006). As a secondary physics student assumes greater responsibility to diagnose their learning needs, to strategize on how to acquire necessary knowledge, and to set personal learning goals, they are developing critical college and career survival skills supplemental to the mastery of foundational physics concepts (Guglielmino, 2000).

Recommendation 1: As Bloom (1968) so eloquently conveyed, time is the variant to mastery, not ability. Successful students invested triple the time in formative testing versus unsuccessful students. Chickering and Gamson (1991, p. 66) said it well, "There is no substitute for time on task. Learning to use one’s time well is critical for students and professionals alike." By choosing easier tasks and hurriedly completing them, unsuccessful honors students compromised their learning. The first important parallel instruction centers on the importance of teaching time management skills with goal setting in addition to the regular curriculum, and helping students realize that schema development is a process and takes time (Bransford, 2000; Gagne, 1988).

Recommendation 2: DeCorte (2000) states the degree of students' self-regulation correlates strongly with academic achievement. Capstone results indicated that successful students exhibited SDL readiness, while unsuccessful students showed less metacognition and commitment to the learning process (as evidenced by 25% less time investment and fewer attempts at retaking the unit test). The 17 unsuccessful honors students would have benefited from explicit instruction in SDL attitudes and behaviors. The core attitude must be that the student is ultimately responsible for and controls their learning (Bolhuis, 2003; Bransford, 2000; Breslow, 2003; Gibbons, 2003). Pape (2000) encourages instructors to explicitly teach Learning to Learn strategies, such as using feedback to grow, actively listening and reading, maintaining a success-orientation, avoiding procrastination, and preparing for exams. To foster positive attitudes towards learning and motivation, Pape, Bell & Yetkin (2003) and Weiser (2005) promote the value of student journals and post-test surveys to help students associate effort and disposition with grades. Verschaffel (1999) recommends that instructors model problem-solving strategies for students and requires group practice as part of the process. The second important parallel instruction involves teaching Learning to Learn and other SDL strategy techniques in concert with content instruction.

Recommendation 3: Bolhuis (2003) effectively distills these parallel instruction ideas into striking a balance between content-oriented and process-oriented instruction. Bolhuis (2003) states instruction will foster SDL if four principles are addressed. The first is the need to maintain a healthy “constructive friction” and move gradually to SDL, because learners differ in readiness (p. 339). A continuum exists between teacher-directed learning and self-directed learning for each learner (Breslow, 2004; Gibbons, 2002). The second is to focus on building content knowledge by making the learning more meaningful, particularly through the use of problem-based learning. Several authors recommend anchoring instruction around a real-world problem because it establishes a framework and relevance for the learning (Jonassen, 2003; Merrill, 2007; Merrill & Gilbert, 2008). The third principle is to pay attention to the emotional aspects of learning by providing positive feedback, helping students to embrace uncertainty, fostering motivation, and modeling the reward of solving hard problems. The final principle is to treat learning as a social phenomenon and facilitate social skills and effective cooperative learning. Merrill and Gilbert (2008) emphasize that learning is a social phenomenon and delineate helpful peer interactions for the different stages of learning. Bolhuis’ (2003) content- and process-oriented instruction provides a multidimensional perspective to teaching.   Future work will implement modeling, more intentional peer interactions, and more explicit SDL strategy instruction in parallel with content instruction and the outcomes will be evaluated.

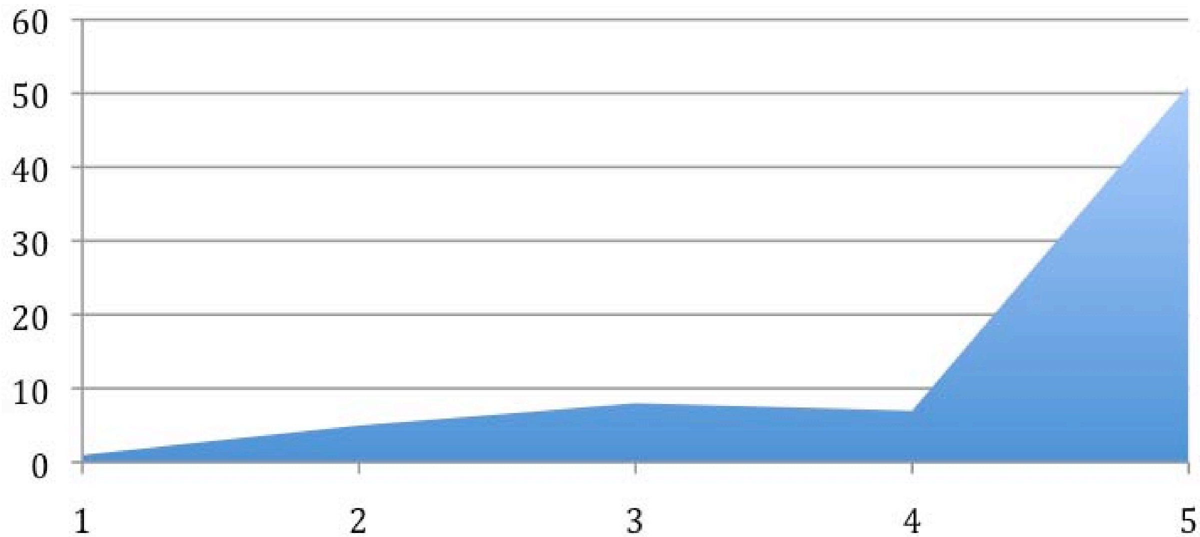

Figure 5-1. Epilogue: Gains in average unit test scores over five tests. Gain was calculated as [(Recent Score – Previous Score) / (100 – Previous Score)].

APPENDIX A
TIME TICKET

Daily Time Ticket

Take a moment to document how you used your class time today.

Your username (**wathens@ecsphysics.org**) will be recorded when you submit this form. Not **wathens**? Sign out

* Required

Identify which unit activities you worked on today. *

Estimate the time you spent in that activity by clicking the appropriate button.

	0 min	10 min	20 min	30 min	40+ min
masteringphysics.com	○	○	○	○	○
PhET - Energy Skate Park	○	○	○	○	○
ExploreLearning's Energy Conversion in a System	○	○	○	○	○
Design a Roller Coaster SW	○	○	○	○	○
Pendulum experiment	○	○	○	○	○
KE <=> PE Quiz	○	○	○	○	○
Read and outline Ch 11	○	○	○	○	○
Work Ch 11 standardized test questions (paper)	○	○	○	○	○
Wildcard activity	○	○	○	○	○
Rube Goldberg project	○	○	○	○	○
Taking unit test	○	○	○	○	○

Which types of support did you use today? *

Estimate the time you spent with that support type by clicking the appropriate box.

	0 min	10 min	20 min	30 min	40+ min
Instructor	○	○	○	○	○
Peer	○	○	○	○	○
Computer	○	○	○	○	○

☑ Send me a copy of my responses.

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APPENDIX B
POST STUDENT SURVEY

Post Student Survey
Conservation of Energy Unit

Instructions: This is a questionnaire designed to gather data on preferences and attitudes towards learning physics. After reading each item, please indicate the degree to which you feel that statement is true of you. There are no right or wrong answers. Please read each choice carefully and choose the response which best expresses your feeling. Your answers are CONFIDENTIAL and will only be presented as pooled data.

There is no time limit for the questionnaire. Try not to spend too much time on any one item; however, your first reaction to the question will usually be the most accurate.

PART A: These items generally relate to learning physics.

Responses

1 = I hardly ever feel this way.
2 = I feel this way less than half the time.
3 = I feel this way about half the time.
4 = I feel this way more than half the time.
5 = There are very few times when I don't feel this way.

Items

1. A significant problem in learning physics is being able to memorize all the information I need to know.

2. When I am solving a physics problem, I try to decide what would be a reasonable value for the answer.

3. It is useful for me to do lots and lots of problems when learning physics.

4. I think about the physics I experience in everyday life.

5. Knowledge in physics consists of many disconnected topics.

6. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

7. To do well in this physics course, I need to see sample problems like those on the tests.

8. I cannot learn physics if the teacher does not explain things well in class.

9. I am developing general problem solving techniques in this course.

10. In a learning experience, I prefer to take part in deciding what will be learned and how rather than having the teacher tell me what to do.

11. Difficult study doesn't bother me if I'm interested in something.

12. No one but me is truly responsible for what I learn.

13. I can tell whether I'm learning something well or not.

14. Understanding what I read is a problem for me.

15. If I discover a need for information that I don't have, I know where to go to get it.

16. If I experience a difficulty while studying physics, I try to figure it out on my own.

17. To understand physics I discuss it with friends and other students.

18. There is usually only one correct approach to solving a physics problem.

19. I do not expect physics equations to help my understanding of the ideas; equations are for doing calculations.

20. The first thing I do when solving a physics problem is make a drawing to represent it.

21. I am not satisfied until I understand why something works the way it does.

22. I enjoy solving physics problems.

23. I do not invest time understanding the derivations of equations.

24. I have found carefully analyzing only a few problems in detail is a good way for me to learn physics.

25. It is possible to explain physics ideas without mathematical formulas.

PART B: These items are specific to the conservation of energy mastery learning environment.

26. I prefer to learn from our Glencoe textbook rather than Internet resources.

27. I prefer traditional lecture with a weekly lab compared to the self-paced VOLO work.

28. I invested significant hours outside of class because I did not have sufficient time during class to learn this material.

29. I have mastered the key ideas about conservation of energy.

30. I am satisfied with my grade for this unit.

31. Retaking the unit test helped me figure out my weak spots, and focused my learning.

32. I developed a learning strategy that worked for me for this unit.

33. Masteringphysics® was very helpful to my learning process.

34. PhET Energy Skate Park was very useful to my learning process.

35. The Pendulum-Box Bash experiment was very useful to my learning process.

36. This unit had the right balance of whole-class, small-group, and individual learning activities.

37. I had all the support I needed – whether from the teacher, peers, or course resources – to learn this material.

38. Some class periods I accomplished very little.

39. I have a very productive team in this course.

40. I had a plan for what I wanted to accomplish each day *BEFORE* I entered the physics classroom.

PART C: Open response questions about the conservation of energy mastery learning environment.

41. Three VOLO activities were required – masteringphysics, PhET Energy Park, and the Pendulum-Box Bash experiment. Explain why you chose the other two VOLO activities that you did, identify them, rate how much you enjoyed them, and rate their usefulness to your learning. Use the scale of 1 (low) to 5 (high).

42. Describe how accessible your teacher was in meeting your learning needs, and rate the quality of that support on a scale of 1 (low) to 5 (high).

43. Describe how accessible your peers were in meeting your learning needs, and rate the quality of that support on a scale of 1 (low) to 5 (high).

44. If you had a choice of two tools or resources to use to learn physics, what would you pick and why?

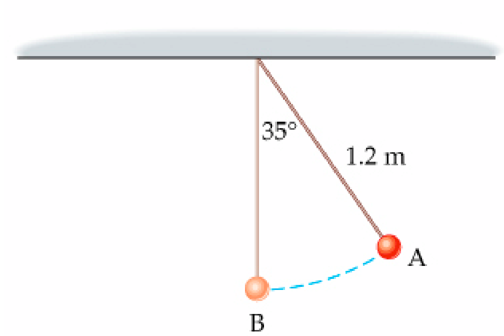
45. Comment on the mastery learning approach, which includes frequent tests with feedback from instructor and peers, followed by taking corrective actions before retesting. Do you learn more in this approach than in traditional courses?

APPENDIX C
SAMPLE TEST

Honors Physics
Conservation of Energy Test

For each problem or question on the right, show your work on the left, clearly mark your answer, and remember significant figures and units.

Answer	***Problem / Question***
1	1. A spring with a spring constant of 4.0 N/m is compressed with a force of 1.2 N. What is the total elastic potential energy stored in this compressed spring?
2.	2. Suppose in Problem #1, you were not given the value of the spring constant. Explain how you can determine the value of the spring constant.
3.	3. Two blocks of ice, one four times as heavy as the other, are at rest on a frozen lake. A person pushes each block the same distance. Ignore friction and assume that an equal force is exerted on each block. Compared to the speed of the heavier block, how fast does the light block travel?

Answer	***Problem / Question***
4	4. A person is standing in an elevator, which is moving upward at a *constant speed*. Consider the person as a system. As the elevator goes between the 3rd and 4th floor, (a) The total work done on the person by the elevator and the Earth is positive. (b) The total work done on the person by the elevator and the Earth is zero. (c) The total work done on the person by the elevator and the Earth is negative. (d) Not enough information to determine ***V.***
5a.	5. A roller coaster car has a mass of 290 kg. Starting from rest, the car acquires 3.13E5 J of kinetic energy as it descends to the bottom of a hill in 5.3 seconds. a. Calculate the height of the hill.
5b.	5b. What is the speed of the car at the bottom of the hill?
6.	6. A pendulum experiment is conducted with a 0.35-kg bob that is moving to the right at 2.7 m/s. What is the bob's speed at point A? 

APPENDIX D
IRB

Appendix G
UFIRB 02 – Social & Behavioral Research
Protocol Submission Form

This form must be typed. Send this form and the supporting documents to IRB02, PO Box 112250, Gainesville, FL 32611. Should you have questions about completing this form, call 352-392-0433.

Title of Protocol:	**Use of Google® Apps platform to create a mastery learning environment**		
Principal Investigator:	**Wendy Athens**		**UFID #:** [redacted]
Degree / Title:	**M.S., Ed.D candidate in Educational Technology**	**Mailing Address:** (If on campus include PO Box address): [redacted]	**Email:** wjathens@ufl.edu
Department:	**College of Education** **Department of Educational Technology**		**Telephone #:** [redacted]
Co-Investigator(s):		**UFID#:**	**Email:**
Supervisor *(If PI is student)*:	**Dr. Kara Dawson**	**UFID#:**	
Degree / Title:	**Associate Professor of Educational Technology**	**Mailing Address:** (If on campus include PO Box address):	**Email :** dawson@coe.ufl.edu
Department:	**College of Education** **School of Teaching & Learning** **Department of Educational Technology**	**P.O. Box 117048 Gainesville, FL 32611-7058**	**Telephone #:** **352-392-9191 x261**
Date of Proposed Research:	**January – February 2011**		
Source of Funding *(A copy of the grant proposal must be submitted with this protocol if funding is involved):*			

Scientific Purpose of the Study:

This study will be conducted in my 11th & 12th grade honors physics classroom (N = 25) at Evangelical Christian School in Fort Myers, FL, for a design-based research effort that will serve as my Ed.D. capstone project. The purpose of this study is to assess learning gains within a 21st century mastery learning environment over a six week period in January and February 2011. More specifically, I seek to identify expert/peer/computer-tutor time required by each student to meet his or her individual learning goals. To do this, I employ Google® Apps and web tools. Students learn through a largely self-paced program, and the time the student spends with the expert, peer, and computer tutor will be tracked. I will correlate these three times with performance on the Force Concept Inventory test (FCI, Attachment 1), a validated instrument that probes conceptual understanding, and also course performance. I will collect weekly learning blog data from the students. I will also collect data from the validated Values about Science Survey (VASS, Attachment 2). An auxiliary investigation is the correlation between student learning styles and learning tasks selected.

Describe the Research Methodology in Non-Technical Language: *(Explain what will be done with or to the research participant.)*

During three learning units of approximately six weeks duration students will track the tutorial resources they use to learn, whether expert, peer, or computer. The learning unit structure is designed as follows: two days of whole-class, face-to-face instruction followed by the balance of self-paced work. The whole-class phase introduces the major concepts for the unit, engages the students in an inquiry activity, and demonstrates and models the problem-solving skills to be developed. Students are then presented with a list of nine learning options of which they must complete five to receive the highest grade. Students submit a learning contract to the instructor by placing the digital contract on their personal web page. Some learning options are required, such as the masteringphysics® homework tutorial problem set, a type of computer tutor, which requires typically 1.5 hours to complete.

Students then begin self-paced work, encompassing approximately seven days. Approximately halfway through this time students take a formative assessment. This is a prescriptive assessment which provides necessary feedback, and the instructor suggests corrective pathways. This is the heart of mastery learning: assessment-feedback-corrective cycles. Students access all course resources, manage their e-portfolio, and track their time through the class website, which is a Google® Apps for Education website. All students have a personal web page within the class website, which holds their learning contracts, physics learning blog, and an electronic file cabinet to collect their work (e-portfolio). Every student has editor capability for the "expert tutor" calendar to schedule one-on-one time with the teacher in advance of class. Every student has Google® Groups and Gmail capability, which facilitate peer collaboration.

Towards the end of the learning unit, students take a summative assessment. This assessment takes approximately 25 minutes to complete (10 questions), and if the student does not score at least an 80%, he or she must retake a similar assessment tool. The assessments are graded one-to-one with the instructor to receive essential feedback and target areas for improvement.

The learning unit concludes when the students have completed their learning contracts and scored at least an 80% on the unit test. Grades are allocated as follows: 45% learning contract completion, 45% test, and 10% blogs. The conservation of energy unit includes a project (Rube Goldberg contraption), which counts for a test. At the conclusion of the three learning units, students complete the post-FCI and VASS.

Describe Potential Benefits: The purpose of this study is to demonstrate viability of 21st century technologies to enable mastery learning, a proven instructional practice with learning gains typically in the 1-2 sigma (standard deviation) range. The 21st century technologies to be investigated include Google® Apps, computer tutors (including masteringphysics®), and web tools (including PhET from University of Colorado at Boulder and MOPS from Glenbrook South High School in Glenview, IL.) By tracking which tutor resources the student uses – expert, peer, and computer – a correlation can be drawn between concept mastery and the form of tutor support utilized, if at all. Since the ideal is to simulate a one-to-one tutor relationship in a whole-class setting, correlations between learning success and the amount of individual tutoring time can be explored, as well as the success of substituting a computer tutor for a human tutor. The overall goal of this study is to improve performance on the FCI compared to performance of similar classes in two prior years. An auxiliary study involves a chi-square analysis between students' learning styles (students completed a learning style analysis earlier in the school year) and the learning options selected within the unit learning contracts. A third benefit anticipated from this study is the contribution to two bodies of literature, namely physics education research and blended secondary learning environments.
Describe Potential Risks: (*If risk of physical, psychological or economic harm may be involved, describe the steps taken to protect participant.)* There are no risks to this study. Students will enjoy working independently and in small groups and with more one-on-one time with the teacher. No individual identities will be revealed in the reporting of this research.
Describe How Participant(s) Will Be Recruited: All students in ECS Honors Physics will be participate in the mastery learning environment, and at the conclusion of the two learning units, a consent letter will be sent to parents and students for permission to include their anonymous data in the capstone document and publications.

Maximum Number of Participants (to be approached with consent)	**25**	**Age Range of Participants:**	**16-17**	**Amount of Compensatio n/ course credit:**	**N/A pertaining to the study itself, but the learning units covered during the study do constitute partial fulfillment of 1.5 credits of science**

Describe the Informed Consent Process. (Attach a Copy of the Informed Consent Document. See http://irb.ufl.edu/irb02/samples.html **for examples of consent.)**

(SIGNATURE SECTION)		
Principal Investigator(s) Signature:	**Wendy Athens**	**Date: 11-24-10**
Co-Investigator(s) Signature(s):		**Date:**
Supervisor's Signature (if PI is a student):		**Date:**
Department Chair Signature:		**Date:**

UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation

28 February 2011

Dear Parent/Guardian:

I am a doctoral candidate in the Educational Technology program at the University of Florida, conducting research on the use of technology to enable mastery learning under the supervision of Dr. Kara Dawson. This research was conducted in two sections of ECS Honors Physics in January and February. The research ideal was to simulate a one-to-one tutor relationship in a whole-class setting, and correlations between learning success and the amount of individual tutoring time was explored as well as the success of substituting a computer tutor for a human tutor. The overall goal of this study was to improve long-term conceptual understanding in physics, and two measures of this were the course grade as well as performance on a nationally recognized conceptual physics test called the Force Concept Inventory. An additional aspect of this study involved seeking a relationship between students' learning styles (students completed a learning style analysis earlier in the school year) and the learning options chosen for each unit.

All students participated in the mastery learning environment; however, only with your consent will I include *anonymous* data from your son/daughter in the publications associated with this research. The type of data to be included in publications includes:

- time spent with a computer/peer/computer-tutor
- anonymous trends noted in students' weekly physics learning blogs
- anonymous results to the Force Concept Inventory test
- anonymous course grades
- anonymous results to the Values about Sciences Survey
- pooled data only on learning styles in the classroom
- pooled data only on learning options chosen for each unit.

Although I believe this study will help your student and future students learn physics better, a choice to not participate will not affect your student's grade. In fact, I waited until the end of the learning units so your response would in no way influence your student's grade nor bias my records. There are no known risks or immediate benefits to the participants, and no compensation is offered for participation.

Again, no student names will ever be reported. All results will be expressed as group data. This study will most likely be published in a science education journal and presented at a technology conference. Study results will be available after May 2011. To receive a copy of results or to ask questions, contact me at wathens@goecs.org. Questions or concerns about your child's rights as research participant may be directed to the IRB02 office, University of Florida, Box 112250, Gainesville, FL 32611, (352) 392-0433.

Wendy Athens
Wendy Athens

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BIOGRAPHICAL SKETCH

> Innovation comes from having two or more specialties and applying the framework of one specialty to the framework of another. (Friedman, 2008)r

In his *The World is Flat 3.0* lecture at MIT, Thomas Friedman (2008) encouraged 'mash-ups' of skill sets as a way to contribute to society. Wendy Athens' mash-up of expertise combines science (specifically chemistry and physics), technology, and education within a worldview of social constructivism. Her expertise in secondary science stems from her undergraduate and graduate work in chemistry, seven years of experience in the chemical instruments and computer business while at Hewlett-Packard, and seven years in secondary chemistry and physics education. She refined her understanding of effective integration of technology in the classroom by conducting her own classroom research while simultaneously completing the doctoral program in educational technology within the School of Education at the University of Florida.

Her interest in self-directed mastery learning originated from her motivation to develop [big view] America's talent in science and technology by [small view] better developing her students. Bloom's original writing on mastery learning was eloquent and compelling, and its implementation was proven effective over decades of evaluation (Bloom, 1968; Gagne, 1988). Wendy hoped that technological innovation would make the integration of mastery learning protocols in her classroom easier and thereby free her to invest more one-to-one time with students thus providing more individualized feedback and instruction. This led to the need for SDL activities to productively occupy others while she tutored, which birthed the VOLO. The VOLO idea developed while reading differentiated instruction literature that encouraged choice in learning activities.

Wendy believes the Google® Apps/VOLO infrastructure of this capstone project was a complete success and she will continue to use it. She will fine-tune the program with the selection of VOLO activities, the FTF/online balance, the whole-class/small-group/individual balance, and by tweaking the allocation of points to stress concept development. But refining the infrastructure is easy compared to the real challenge of incorporating explicit instruction in SDL strategies into the curriculum. She believes the contrast between successful and unsuccessful students in this capstone made it very clear: There are no shortcuts to learning. "Time plus effort equals learning" (Chickering & Gamson, 1991, p. 66). To better equip students to be successful in her physics courses and beyond, she must simultaneously teach on a supplemental plane to science; specifically, she must foster development of SDL skills.