10-24-2011

A Gender Study Investigating Physics Self-Efficacy

Vashti Sawtelle
Physics, vashti.sawtelle@gmail.com

DOI: 10.25148/etd.FI11120705

FLORIDA INTERNATIONAL UNIVERSITY

Miami, Florida

A GENDER STUDY INVESTIGATING PHYSICS SELF-EFFICACY

A dissertation submitted in partial fulfillment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY

in

PHYSICS

by

Vashti Sawtelle

2011

To: Dean Kenneth Furton
College of Arts and Sciences

This dissertation, written by Vashti Sawtelle, and entitled A Gender Study Investigating Physics Self-Efficacy, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

Laird H. Kramer

Bernard S. Gerstman

David T. Brookes

Suzanna M. Rose

Eric Brewe, Major Professor

Date of Defense: October 24, 2011

The dissertation of Vashti Sawtelle is approved.

Dean Kenneth Furton
College of Arts and Sciences

Dean Lakshmi N. Reddi
University Graduate School

Florida International University, 2011

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grants No. 03120038, and No. 0802184. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

I would like to acknowledge my dissertation advisor, Eric Brewe, who provided the motivation and insight to make this work possible. I would also like to acknowledge Laird Kramer as an instrumental influence in my graduate career. I am grateful to the other members of my committee: David Brookes, Bernard Gerstman, and Suzanna Rose. I would like to thank the faculty members and students who participated in my studies.

I have been fortunate to be a member of an excellent Physics Education Research Group while conducting my research. My work has been strengthened by the discussions and critiques from them. Many hours of discussions with Idaykis Rodriguez were integral to shaping my dissertation work and my ideas about diversity and equity. The patient guidance of Renee Michelle Goertzen was invaluable in completing the video analyses.

Finally, a heartfelt thanks goes to: my husband, Jim; my parents, Lisa and Jim; and my in-laws, Brad and Mary. Without their support this work would never have begun.

Chapter 3 has been reprinted with permission from V. Sawtelle, E. Brewe, and L. H. Kramer, "Positive impacts of modeling instruction on Self-Efficacy," in Proceedings of the 2010 Physics Education Research Conference, Portland, OR (AIP, Melville, NY, 2010), p. 289. Copyright 2010, American Institute of Physics.

ABSTRACT OF THE DISSERTATION

A GENDER STUDY INVESTIGATING PHYSICS SELF-EFFICACY

by

Vashti Sawtelle

Florida International University, 2011

Miami, Florida

Professor Eric Brewe, Major Professor

The underrepresentation of women in physics has been well documented and a source of concern for both policy makers and educators. My dissertation focuses on understanding the role self-efficacy plays in retaining students, particularly women, in introductory physics. I use an explanatory mixed methods approach to first investigate quantitatively the influence of self-efficacy in predicting success and then to qualitatively explore the development of self-efficacy. In the initial quantitative studies, I explore the utility of self-efficacy in predicting the success of introductory physics students, both women and men. Results indicate that self-efficacy is a significant predictor of success for all students. I then disaggregate the data to examine how self-efficacy develops differently for women and men in the introductory physics course. Results show women rely on different sources of self-efficacy than do men, and that a particular instructional environment, Modeling Instruction, has a positive impact on these sources of self-efficacy. In the qualitative phase of the project, this dissertation focuses on the development of self-efficacy. Using the qualitative tool of microanalysis, I introduce a methodology for understanding how self-efficacy develops moment-by-moment using the lens of self-efficacy opportunities. I then use the characterizations of self-efficacy opportunities to focus on a particular course environment and to identify and describe a mechanism by which Modeling Instruction impacts student self-efficacy. Results indicate that the emphasizing the development and deployment of models affords opportunities to impact self-efficacy. The findings of this dissertation indicate that introducing key elements into the classroom, such as cooperative group work, model development and deployment, and interaction with the instructor, create a mechanism by which instructors can impact the self-efficacy of their students. Results from this study indicate that creating a model to impact the retention rates of women in physics should include attending to self-efficacy and designing activities in the classroom that create self-efficacy opportunities.

TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

CHAPTER 1 INTRODUCTION

1.1 Motivation

In 2005, members of Congress requested that the National Academies conduct a formal study on America's competitiveness in science and technology. In response, the National Academies initiated a study and established a committee to produce a report on the issue. The committee, composed of a number of university presidents, Nobel laureates, corporate executives, and former presidential appointees, produced a report on the current state of science and technology education entitled "Rising Above the Gathering Storm" [1]. This report listed four measures the country should take in order to remain competitive in a global marketplace. One of these measures focused on increasing the number of science, math, and engineering (STEM) degrees produced in the country. In 2010, members of this committee followed up on the status of the proposal and found that the number of STEM degrees still remains a critical point for maintaining the competitive ability of the United States in a global marketplace [2].

In terms of bachelor's degree production, the United States has steadily increased the number of STEM degrees fields over the past decade [3]. However, within STEM fields, physics makes up less than 2% of all the bachelor's degrees awarded. Further, when looking at underrepresented groups, we see minorities, women, and women minorities are a highly untapped resource in physics. Women make up only 21% of the bachelor's degrees awarded in physics, which is dismal when compared with the proportion of women making up the degrees awarded in chemistry (50%), biological sciences (61%), and mathematics (46%). Only the fields of engineering (20%) and computer sciences (24%) are comparable to physics with the lack of female representation in the number of degrees awarded [3].

Furthermore, when we look at the participation of women who are ethnic minorities in physics we see an even larger untapped resource. Black women make up only 1.3% of the bachelor's degrees in physics, and Hispanic women make up less than 1%. Although women of color are by no means equitably represented in any of the sciences, their representation in physics is particularly low as demonstrated by the proportion of Hispanic and Black women in chemistry (4.0%, 5.2%) and the biological sciences (4.5%, 5.5%) [3]. Over the period between 2000 and 2008, the United States has seen a nearly 50% increase in the number of bachelor's degrees awarded to Hispanic women and nearly 37% increase in Black women [3]. While physics has been keeping pace with this increase, ethnic minority women remain a largely untapped resource for expanding the representation of physicists.

The Center for High Energy Physics Research and Education Outreach (CHEPREO) program at Florida International University (FIU) was developed in part in an attempt to increase the representation of underrepresented groups in physics. Florida International University is a Hispanic serving institution with the Hispanic population making up 60.4% of the enrollment in 2010, making it an excellent place for targeting the largely untapped resources of women and ethnic minority students. Particularly the Physics Department, in part because of the influence of CHEPREO, has targeted these groups. In 2010, FIU had 126 declared physics majors of which 84 (67%) were Hispanic, and 28 (22%) were female [4]. CHEPREO's effort to increase participation by underrepresented groups in the physics major has centered on reforming the introductory physics sequence. At FIU, students have the option of taking either a traditional Lecture-format course for introductory physics, or a the reformed Modeling Instruction course that focuses on conceptual understanding in an integrated laboratory and lecture environment [5]. The Physics Education Research Group at FIU has been engaged in implementing and understanding the successes of the Physics Department and the CHEPREO program particularly in indentifying what factors play a role in contributing to the acquisition and retention of underrepresented students in physics.

My study focuses on understanding how the dimension of self-efficacy can be used to understand retention and success of students in physics. Self-efficacy, or the confidence in one's ability to succeed in a task, has been linked to student persistence and success in various fields of science and mathematics [6]. However, little work has been done concerning self-efficacy in physics, and what has been done has often led to conflicting conclusions. As such, my study focuses on understanding how self-efficacy can be used to predict the retention and success of both women and men in introductory physics at this large Hispanic serving institution, and how self-efficacy develops within this course. I have chosen introductory physics as my focus primarily because nearly all science majors (as well as engineering) require introductory physics, in addition to the physics major. As a result, this course serves as a gateway to persistence in physics as well as to persistence in participation in the larger body of sciences. Additionally, the introductory course provides a large sample size for investigating the influence of self-efficacy on retention. Further, while I do not explicitly discuss the role of ethnicity in this study I acknowledge that the majority of participants are Hispanic, and thus part of the historically underrepresented groups in physics. As a result, although I focus my attention in this study primarily on the issue of gender, the majority of the students also represent a resource for increasing participation of underrepresented minorities in physics. In the present thesis I begin by understanding the role self-efficacy plays in predicting the success of both men and women in Introductory Physics. I follow this by investigating how self-efficacy develops within the particular context of Modeling Instruction using a method of identifying self-efficacy opportunities.

1.2 Large Scale Literature Review and Theoretical Framework

In this section I broadly summarize the research relating to gender equity and the success of women in the sciences, propose a reframing of the discussion through social cognitive theory and provide a brief review of self-efficacy literature. A more detailed discussion of the relevant literature will be provided in the following chapters.

The primary focus of the literature in gender equity in the sciences has been on understanding the barriers that women face in choosing to pursue a science major or career. Much of the literature on gender equity in science, and particularly in physics, has centered on characterizing the existing gaps between the scores on various assessments of women and men [7--11]. However, a shift took place in the 1980's that moved towards creating gender-inclusive classrooms [12]. This research worked under the assumption that increasing the participation of women in science could be achieved by improving the way science is taught. The literature, as a result, characterizes the differences in experiences between women and men and what methods in the classroom appear to be most effective for girls [10,13,14]. Implicit in much of the literature on gender and equity in science is a focus on why underrepresented students do not choose to pursue science careers and/or majors. This focus, particularly when the work uses comparison of groups, can easily lead to deficit model thinking, or the assumption that European male behavior is the norm and that women need to perform at the standards of the normative group [15]. Implicitly in these studies the researchers are asking what makes students who choose not to pursue science different from those who do choose science, and attempt to 'fix' those students by adding in the missing ingredient. Comparing individuals to the desired 'norm' of those who pursue science degrees implies simplistic answers that do not necessarily capture the larger sense and understanding of the data [14,16]. For example, if a study finds that students who earn science degrees have significantly higher Scholastic Achievement Test (SAT) scores than students who do not pursue science, the interpretation might focus on bringing up the SAT scores in order to increase persistence in science. In focusing on this need to 'fix' the non-science students, the researchers may not see other issues that contribute to decisions to not pursue science such as the lack of opportunity to form relationships with others [14], the desire to take something back to their communities [17], or the pieces of identity that are perceived to be at odds with pursuing science [18].

In an effort to avoid deficit model thinking, I shift the focus of my research from finding reasons why students do not choose to pursue physics, to understanding how we might support students in the decision to choose a physics major/career. The shift in focus comes with the acknowledgement that individuals make decisions about the actions that they will take, and that these actions are not dictated simply by external factors. Social Cognitive Theory (SCT) [19] provides a framework for my dissertation research. Social Cognitive Theory posits that humans are, in part, designers of the actions they take (only in part because human behavior is the result of several interacting factors) and that no mechanism of human agency is more central to these decisions than personal efficacy beliefs. Subscribers to SCT suggest the underrepresentation of women may be the result of beliefs they hold about their capabilities [20]. Efficacy beliefs hold a prominent position in SCT as they dictate what tasks people choose to undertake, how much effort they expend on the task, whether they will persist in the face of adversity, and what level of interest the task holds for them [19].

As self-efficacy beliefs play such a prominent role in understanding the choices that individuals make, Bandura has expanded upon the theory of the role self-efficacy plays and how it develops [19,21]. In his treatise on human behavior change he proposed that self-efficacy develops from four types of experiences: personal *mastery experiences*, *vicarious learning* experiences, *social persuasion* messages, and one's *physiological state* [21]. Since its introduction, much of the research on self-efficacy has primarily followed two complementary paths: using the rating of an individual's confidence in capability to predict success or persistence on specific tasks; or influencing and understanding how self-efficacy beliefs develop. Self-beliefs of capability, or self-efficacy, have been shown to play a powerful role in predicting the likelihood of individuals to persist in science majors [22--24], and academic success in mathematics and the sciences [6,25,26]. In investigating how self-efficacy develops for individuals, the research has primarily focused on looking for groups that rely on specific sources of self-efficacy [20,27--29]. Yet, little research has been done on the influence of self-efficacy on persistence in physics in either of these two paths. As a result, the first portion of this thesis focuses on the role self-efficacy plays in predicting the success of students in introductory physics. In the second part, I will discuss the development of self-efficacy as a way of targeting the self-beliefs of diverse students. Finally, I investigate how a particular physics classroom environment develops student self-beliefs of capability.

1.3 Overview of the Thesis Project

1.3.1. Purpose of the Thesis Project and Research Questions

The goal of this research project is to understand the role self-efficacy plays in increasing the retention of underrepresented groups, particularly women, in physics. As discussed above, I focus my work on the introductory physics classroom as it represents a gateway to both the physics major and continued participation in the sciences. In particular, much of my work discusses the impact of a particular classroom environment, Modeling Instruction, that has been successful in both retaining underrepresented groups of students [30] and impacting physics self-efficacy [31]. I begin by studying the ability of students' incoming self-efficacy beliefs to predict success in the classroom. The results show that self-efficacy is a good predictor of success in the introductory physics classroom for all students, yet the sources of this self-efficacy that best predict the success of men and women are different. Next, I investigate the impact of two different course types on the development of self-efficacy. I find that Modeling Instruction positively impacts self-efficacy for all students, and particularly for the *social persuasion* source development for women. The second phase of my work, as a result, focuses on understanding how students develop self-efficacy. I frame this discussion as an analysis of opportunities to impact self-efficacy as events unfold moment-by-moment, and demonstrate this as an effective method for investigating self-efficacy in real-time.

Finally, I focus my attention on how Modeling Instruction, as an example of a highly successful course, provides a variety of opportunities to develop self-efficacy.

In this dissertation I address the following research questions:

1) What role does self-efficacy play in retaining students in introductory physics?
2) How can self-efficacy be used to understand the improved retention rates of women in the Modeling Instruction course as compared to traditional Lecture-format courses?
3) How do self-efficacy experiences contribute differently to the success of women (as an underrepresented group in physics) and men in the first semester introductory physics course?
4) In what ways does Modeling Instruction mediate changes in self-efficacy for students?

1.3.2. Methodological Approach

The methodology for this thesis is primarily a mixed-methods approach. This research design necessarily includes both philosophical assumptions and particular methods of investigation [32]. The basic assumption underlying the mixed methods approach is that we can gain a better understanding of a research problem by combining both qualitative and quantitative methods than by using one method alone. In this study I use an *explanatory design* [32], which takes place in a two-phase process and fundamentally uses qualitative methods to expand and extend initial quantitative results. Specifically, I use the follow-up explanations model to extend the findings on the role self-efficacy plays in predicting success to understanding how to identify events that represent opportunities to influence self-efficacy.

In Chapter 2, I use data from two semesters of the class to construct models of how self-efficacy predicts the success of both men and women in the course. I use a sequential logistic regression technique that predicts the passing rate of introductory students using a combination of continuous and categorical variables while capitalizing on prior research. I check the validity of this model by comparing outcomes with data collected from a third semester of the course that was not included in the originally modeled data.

I follow this study by investigating the impact of course type on self-efficacy from the beginning to the end of the first semester of introductory physics in Chapter 3. I use data from three semesters of Lecture and Modeling Instruction classes, and use *t*-tests to compare results from the PRE semester survey to the POST semester survey. I further disaggregate the results into the four sources of self-efficacy, and by gender, to investigate the impact of each course on the development of self-efficacy for women. I followed this investigation with a qualitative study designed to understand how self-efficacy develops in a physics classroom.

In the process of understanding the development of self-efficacy, I found it necessary to develop a technique that would allow us to analyze self-efficacy as events were unfolding. To do so, I collected problem-solving data from three female students who were enrolled in a Modeling Instruction section of Introductory Physics with Calculus I. I videotaped these students in a series of four sessions where they were asked to solve progressively more difficult problems. I then used a microanalytic technique [33] to investigate how opportunities to impact self-efficacy unfold moment-by-moment. I used this technique to first verify that I could identify opportunities to impact self-efficacy in real-time (Chapter 4) and then to examine the variety of opportunities that Modeling Instruction provides (Chapter 5). To ensure validity in the qualitative data analysis I used a variety of techniques including triangulation, peer debriefing, and researcher reflexivity [34].

By conducting a mixed methods research project I attempt to strike a balance between generalizability of the results afforded by quantitative data and analysis, and the full and rich descriptions provided by qualitative analysis. However, in striking a balance, I also limit the questions I can answer. For instance, after finding that there are gender differences in the sources of self-efficacy that predict the success of physics students, I did not follow with an examination of the relationship of ethnicity and gender, or by investigating various methods of intervention. Instead, I focused my attention on understanding the details of how particular self-efficacy opportunities are created. Similarly, I did not attempt to expand the findings of the developing self-efficacy opportunities by examining the behaviors of students in various types of courses. While I believe that these directions would be valuable contributions to my understanding, I feel that utilizing a mixed methods approach allowed us to develop a compelling argument for the development of self-efficacy as a way of supporting and retaining women in introductory physics, and to provide opportunities for future work.

1.3.3. Overview of the Dissertation

In this section I provide a brief overview of this thesis by briefly describing the studies and findings of each chapter. The organization of this dissertation is such that each of the data chapters (Chapter 2, Chapter 3, Chapter 4, and Chapter 5) are written in the format of a research paper either published, currently under review, or in preparation to be submitted for publication. As a result, the details of each of the methods used, and the relevant literature will be discussed thoroughly within each of the chapters. Here I provide the reader with a brief outline of what the subsequent chapters hold, and details as to the journal the chapter is to be submitted to and the format requirements of these publications.

Chapter 2 describes the quantitative component of this study, and is a paper currently under review at the Journal of Research in Science Teaching, which requires a modified American Psychological Association reference format [35]. I describe the important role self-efficacy plays in predicting the success of both men and women in Introductory Physics I with Calculus. I first describe a model that identifies self-efficacy as a predictor for all students together in addition to other known indicators of success. I then turn to examining the data for differences in the sources of self-efficacy that serve as good predictors of success for men and women. In doing so, I construct two distinct models for men and women and use the literature to guide the order of entering the sources of self-efficacy into each model predicting success. The findings suggest that the success of men is best predicted by personal *mastery experiences* while women rely primarily on *vicarious learning* experiences, particularly in the Modeling Instruction environment. I discuss the findings of this study as they relate to previous studies in gender equity in science.

In Chapter 3, I use *t*-tests to understand the shift in self-efficacy score in both the Lecture and Modeling Instruction environments. In Chapter 3 I investigate this shift as both an overall shift in self-efficacy for all students, as well as understanding the shift in each source when disaggregated by gender. The findings of this study suggest that Modeling Instruction positively impacts self-efficacy, and has a particularly positive effect on the *social persuasion* source for women. Chapter 3 is published in the conference proceedings of the 2010 Physics Education Research Conference, and thus formatted in the American Physical Society style for references and citations [36]. Further, the conference proceeding publications are limited in page length, and as a result much of the literature review and data collection is summarized in Chapter 3. However, the data collection and primary literature used in this study also appear in Chapter 2.

In Chapter 4, I turn to qualitative methods in order to being an investigation of the mechanism by which self-efficacy develops. This chapter primarily describes a methodology approach I developed to look for opportunities to influence self-efficacy as the event unfolds. In Chapter 4 I describe how the methodology of looking for *self-efficacy opportunities* (*SEO*s) arises from a desire to understand the development of self-efficacy in the present moment, as events are unfolding. I use video recordings of three female Modeling Instruction students solving a physics problem to characterize the *SEO*s through a sources of self-efficacy lens. I validate the characterizations of *SEO*s through bringing the participants back for a post-hoc session where they view the video and describe what they observe happening in the problem-solving sessions. With these data I am able to demonstrate that *SEO*s characterized in the moment-by-moment analysis are taken up and do impact self-efficacy for these students. I discuss this methodology as a way of investigating the development of self-efficacy from an alternative viewpoint. This paper is currently under review at Physical Review Special Topics – Physics Education

Research, which requires an American Physical Society format for references and citations [36].

Chapter 5 extends the use of identifying *self-efficacy opportunities* in a curriculum that is demonstrating success in retaining underrepresented students [30] and in improving self-efficacy [31]. I discuss the key characteristic of Modeling Instruction, namely as a curriculum emphasizing the development and deployment of scientific models, and examine the *SEO*s present when students are engaged in the use of these models. I discuss the variety of *SEO*s I observe as a way that Modeling Instruction supports all students in introductory physics. Chapter 5 is intended for submission to Physical Review Special Topics – Physics Education Research, and as such follows the American Physical Society style guidelines for references and citations [36].

Chapter 6 summarizes the findings across all the previous chapters as results from the larger mixed methods design. In this chapter I discuss how the previous work ties together and what it tells us about the importance of developing self-efficacy for students in introductory physics. Examining the results as a whole I see that self-efficacy is an important component of success for all students in introductory physics, but that the particular way self-efficacy develops varies with gender. We can investigate self-efficacy develop in real-time as events unfold, and this provides us with a mechanism for beginning to understand how Modeling Instruction has been so successful in retaining and supporting underrepresented students in introductory physics. I also discuss implications of this work for future research, and suggest that instead of spending effort on identifying which groups of people rely on which source of self-efficacy, we should focus on providing a variety of experiences for all individuals, which will ultimately develop self-efficacy and support underrepresented groups in physics.

References (Chapter 1)

[1] National Academy of Sciences, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (National Academy Press, Washington, DC, 2005).

[2] N. Augustine, C. Barrett, G. Cassell, N. Grasmick, C. Holliday, and S. Jackson, Washington, DC: National Academy of Sciences, National Academy of Engineering, Institute of Medicine (2010).

[3] National Science Foundation, Division of Science Resources Statistics, *Women, Minorities, and Persons with Disabilities in Science and Engineering: 2011*, Special Report NSF 11-309.

[4] L. H. Kramer (private communication).

[5] E. Brewe, Am. J. Phys. 76, 1155 (2008).

[6] K. D. Multon, S. D. Brown, and R. W. Lent, J. Couns. Psychol. 38, 30 (1991).

[7] J. Blue and P. Heller, in *2003 Physics Education Research Conference, Madison, WI, 2003*, edited by J. Marx, K. Cummings and S. Franklin, (AIP, New York, 2003), p. 45.

[8] L. E. Kost-Smith, S. J. Pollock, and N. D. Finkelstein, Phys. Rev. ST PER 6, 020112 (2010).

[9] L. E. Kost, S. J. Pollock, and N. D. Finkelstein, Phys. Rev. ST PER 5, 010101 (2009).

[10] J. S. Brotman and F. M. Moore, J. Res. Sci. Teach. 45, 971 (2008).

[11] R. Ivie, R. Czujko, and K. Stowe, in *Women in Physics: The IUPAP International Conference on Women in Physics,* edited by B.K. Harline, D. Li, (AIP, Melville, 2002).

[12] D. Baker, J. Res. Sci. Teach. 39, 659 (2002).

[13] A. Roychoudhury, D. J. Tippins, and S. E. Nichols, J. Res. Sci. Teach. 32, 897 (1995).

[14] D. Baker and R. Leary, J. Res. Sci. Teach. 32, 3 (1995).

[15] L. J. Rennie, J. Res. Sci. Teach. 35, 951 (1998).

[16] L. M. Brown and C. Gilligan, Fem. Psychol. 3, 11 (1993).

[17] H. B. Carlone and A. Johnson, J. Res. Sci. Teach. 44, 1187 (2007).

[18] A. T. Danielsson and C. Linder, Gender and Education 21, 129 (2009).

[19] A. Bandura, Annu. Rev. Psychol. 52, 1 (2001).

[20] A. L. Zeldin, S. L. Britner, and F. Pajares, J. Res. Sci. Teach. 45, 1036 (2008).

[21] A. Bandura, *Self-efficacy: The Exercise of Control*, edited by S. F. Brennan and C. Hastings (W.H. Freeman and Company, New York, 1997).

[22] J. Dalgety and R. K. Coll, International Journal of Science and Mathematics Education 4, 97 (2006).

[23] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. 33, 265 (1986).

[24] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. 34, 293 (1987).

[25] S. Andrew, J. Adv. Nurs. 27, 596 (1998).

[26] J. Pietsch, R. Walker, and E. Chapman, J. Educ. Psychol. 95, 589 (2003).

[27] T. Matsui, K. Matsui, and R. Ohnishi, J. Vocat. Behav. 37, 225 (1990).

[28] R. W. Lent, F. G. Lopez, and K. J. Bieschke, J. Couns. Psychol. 38, 424 (1991).

[29] M. A. Hutchison, D. K. Follman, M. Sumpter, and G. M. Bodner, J. Eng. Educ. 95, 39 (2006).

[30] E. Brewe, V. Sawtelle, L. H. Kramer, G. E. O'Brien, I. Rodriguez, and P. Pamelá, Phys. Rev. ST PER 6, 0106 (2010).

[31] V. Sawtelle, E. Brewe, and L. H. Kramer, in *2010 Physics Education Research Conference Proceedings, Portland, OR*, 2010, edited by C. Singh, M. Sabella, and S. Rebello, (AIP, Melville, 2010), p. 289.

[32] J. W. Creswell and V. L. P. Clark, *Designing and conducting mixed methods research* (Sage Publications Inc, Thousand Oaks, CA, 2007).

[33] F. Erickson, *Ethnographic microanalysis of interaction* (Academic Press, San Diego, CA, 1992), p. 201.

[34] J. W. Creswell and D. L. Miller, Theor. Pract. 39, 124 (2000).

[35] Journal of Research in Science Teaching, *Style and Formatting*, Retrieved from: http://jrst-editors.net/authors/guidelines

[36] A. Waldron, P. Judd, and V. Miller, *APS - Physical Review Style and Notation Guide*, 2005, Retrieved from: https://authors.aps.org/STYLE/

CHAPTER 2 PREDICTING SUCCESS USING SELF-EFFICACY

2.1 Abstract

The quantitative results of Sources of Self-Efficacy in Science Courses - Physics (SOSESC-P) are presented as a logistic regression predicting the passing of students in introductory Physics with Calculus I, overall as well as disaggregated by gender. Self-efficacy as a theory to explain human behavior change (Bandura, 1977) has become a focus of education researchers. Zeldin and Pajares (2000) and Zeldin et al. (2008) found evidence that men and women draw on different sources for evaluation of their self-efficacy in science fields. Further, self-efficacy is one of the primary dimensions of students' overall science identity and contributes to their persistence in physics (Hazari, Sonnert, Sadler, & Shanahan, 2010). At Florida International University the physics education research group has examined the self-efficacy of students in the introductory physics classes from the perspective of gender theory, with the intention of understanding the subtleties in how sources of self-efficacy provide a mechanism for understanding retention in physics. In this paper, a sequential logistic regression analysis is used to uncover subtle distinctions in the predictive ability of the sources of self-efficacy. Results indicate that predicting the probability of passing for women relies primarily on the vicarious learning experiences source, with no significant contribution from the social persuasion experiences, while predicting the probability of passing for men requires only the mastery experiences source.

2.2 Introduction

Bachelor's degrees in physics have lagged behind the numbers being awarded in other fields. The latest American Institute of Physics poll found that only 2% of all science, math, engineering, and natural science bachelor's degrees were awarded in physics (Mulvey & Nicholson, 2007). Introductory physics is required for all STEM fields except mathematics, thus one might expect introductory physics courses to draw students into the major. Yet this is not the case, given the low enrollments compared to other STEM majors. Likely contributing to the lack of physics majors is the historical under representation of both women and minorities, which has only improved slightly over the last several decades (Mulvey & Nicholson, 2007). Specifically, Mulvey and Nicholson's statistics on students receiving bachelor degrees show that women only make up about 21% of all of the physics bachelors awarded. When comparing these statistics to other fields like chemistry, math, and other sciences where women enroll in the majors at a rate of nearly 50%, we see that physics is sorely lagging. In order to remain a thriving field in science, physics educators need to focus their attention on increasing the representation of all students in physics, as well as the participation of women and minorities.

The Physics Education Research Group at Florida International University (FIU) in Miami, Florida is engaged in ongoing efforts to increase the number of historically underrepresented students in physics. The primary mechanism in this effort has been reforming the introductory physics course to feature Modeling Instruction (Brewe, 2008). The introductory course has the most enrollment and leverage on student success, thus offers the most impact on undergraduate student careers. The Modeling Instruction courses have succeeded in improving conceptual understanding as compared with traditional lecture instruction, measured using the Force Concept Inventory (Hestenes, Wells, & Swackhammer, 1992), and in retaining women and historically underrepresented minorities at markedly higher rates than traditional instruction (Brewe et al., 2010). However, disaggregation of the FCI scores by gender reveals that Modeling Instruction maintains a conceptual understanding gap (Brewe et al., 2010). Despite the conceptual understanding gap, the odds of success for students from the Modeling Instruction course, including women and historically underrepresented minorities, are 6.73 times the odds of success for students in the traditional lecture course. Contrasting the ever-present learning gap with the persistence of women and historically underrepresented minority students leads to the conclusion that the gap in conceptual understanding of physics cannot fully explain why women and historically underrepresented minorities do not persist in the physics major.

Equity in science literature shows that understanding why women are not persisting in physics is an ongoing research topic for science educators. Researchers in physics education have focused on characterizing the gender gap on conceptual understanding assessments in physics (Blue & Heller, 2003; Hake, 2002; Kost, Pollock, & Finkelstein, 2009, 2010; Miyake, et al., 2010; Robertson, 2006) and ameliorating this gender gap (Brewe et al., 2010; Lorenzo, Crouch, & Mazur, 2006; McCullough, 2004). Gap characterization also pervades the broader science education community (Brotman & Moore, 2008; Ivie, Czujko, & Stowe, 2002). However, since the late 1980's there has been a shift in the literature toward focusing on creating gender-inclusive classrooms (Baker, 2002). These studies suggest that girls are more collaborative and less competitive than boys (Brotman & Moore, 2008; Ferguson & Fraser, 1998; Zohar & Sela, 2003; Ferguson & Fraser, 1998), and prefer learning science in interactive environments (Baker & Leary, 1995). Studies show that girls want a deeper conceptual understanding (Meece & Jones, 1996; Zohar & Sela, 2003), that science classes fail to connect science to real life for women (Lee & Luyx, 2007; Nichols et al., 1998; Roydchury, Tippins, & Nichols, 1995), and that girls and boys have very different out-of-school experiences from a young age (Jones, Howe, & Rua, 2000). Finally, research has shown that the academic science environment is unsupportive of issues, such as balancing work and family life, that are generally important for women (Arnold, 1993; Baker & Leary, 1995; Rosser, 2004). These studies have focused on characterizing the experiences women have primarily in hope of improving the numbers of women who persist in science.

Recent work in this journal has extended these studies, showing a predictive link between *physics identity* and persistence in physics (Hazari, Sonnert, Sadler, and Shanahan, 2010). *Science identity*, as defined by Carlone and Johnson (2007) combines three dimensions: competence, performance, and recognition. Competence and performance stand out in these elements of identity as being related to a student's self-efficacy, or the belief in one's capability to perform a specific task (Hazari, et al., 2010). Self-efficacy, though, is a complex dimension in and of itself, with documented differences between men and women, particularly in the development of self-efficacy (Matsui, Matsui, and Ohnishi, 1990; Zeldin, Britner, and Pajares, 2008; Zeldin, and Pajares, 2000). Thus, in glossing over the complexity of self-efficacy and treating it as a single measure, researchers may be deemphasizing its unique contribution to persistence in physics. The present study will address this complexity by exploring how self-efficacy predicts an individual's retention in a physics course. In the following sections I describe the motivation for identifying self-efficacy as an integral explanatory factor for persistence in physics, particularly for women, and provide evidence for the necessity of exploring this dimension and its relationship to persistence and retention more deeply.

2.2.1. Self-Efficacy

In an effort to provide a theoretical explanation for human behavior change, Bandura (1977) established the framework of self-efficacy. He defined self-efficacy to be the beliefs in one's ability to perform a *specific* task, emphasizing the specificity of the task. As Lent and Brown (2006) describe, self-efficacy is not a single characteristic of an individual, rather self-efficacy is a dynamic set of beliefs that are directly related to a particular task or action. For example, a student may be firmly convinced that they can perform well in a math class, but not feel competent to ask questions of the professor. Although this individual's self-esteem may be stable across both domains, his or her self-efficacy can be very different for the different contexts.

According to Bandura's (1997) social cognitive theory, an individual's self-efficacy is derived from interpreting information from four sources (personal *mastery experiences*, *vicarious learning* experiences, *social persuasion* experiences, and *physiological state*).

Mastery Experiences. Bandura (1986) postulated that people primarily draw on their personal *mastery experiences* (*ME*) to determine their self-efficacy beliefs. Experiences with successful completion of a task should have a strong positive influence on an individual's confidence in their ability to complete a similar task. Analogously, repeated failure on a task would negatively influence a person's confidence in their ability to complete the task later (Bandura, 1997).

Vicarious Learning Experiences. The second source, *vicarious learning* (*VL*) experiences, occurs when an individual watches others, who are perceived to be similar to the individual, performing a task similar to the one they are considering their own performance on. Observing someone else's successes and failures on a task can influence the belief in one's own abilities to perform the similar task. The observation of the success/failure of others is particularly important when the individual has no personal experience with the task at hand because then they rely primarily on their experiences of watching others perform the task (Bandura, 1997; see also Zeldin & Pajares, 2000).

Social Persuasion Experiences. Verbal suggestions from others also influence personal beliefs about abilities. Words of encouragement or social messages can result in an increase in an individual's self-efficacy, thus causing the person to put in extra effort and persistence required to perform a task. However, Bandura (1997) argued that *social persuasion* experiences (*SP*) would have the largest impact on those who already believe themselves capable of performing a task. Nonetheless, verbal and social messages can also discourage beliefs about ability. For example, if women and minorities are continually provided social messages about traditional roles in society, then they may be discouraged about their own abilities to succeed in non-traditional fields (Hackett & Betz, 1981).

Physiological State. Lastly, the *physiological state* (*PS*) acts as a mediating source (Bandura, 1997; Hackett, 1981), working with other sources to amplify or undermine confidence in one's ability to perform a task. High levels of stress and anxiety often undermine any confidence in ability (Bandura, 1997). Mood also often influences beliefs in abilities; cheerfulness and a positive attitude will have a positive effect on self-efficacy beliefs. Analogously, depression and sadness will negatively impact self-efficacy beliefs (Zeldin & Pajares, 2000).

Bandura (1977) hypothesized that expectations of self-efficacy would affect the amount of effort that an individual puts into a task, and how long that effort would be sustained, especially in the face of other obstacles that may arise. Originally, much of the work done on self-efficacy focused on how self-efficacy could be used to treat and ameliorate phobias (Bandura, 1977; Moe & Zeiss, 1982). Since then, however, there has been a significant amount of work investigating self-efficacy in the classroom. Much of the research in education focuses on the self-efficacy of teachers (Enochs, Scharmann, & Riggs, 1995; Schoon & Boone, 1998). The self-efficacy literature also links student science self-efficacy to persistence in science majors and career choices in science (Dalgety & Coll, 2006; Lent, Brown, & Larkin, 1986, 1987, 1989; Luzzo, et al., 1999), as well as to achievement in science for high school students (Britner, 2008; Lau & Roeser, 2002) and students in university classes (Andrew, 1998; Lent, Brown, & Larkin, 1984, 1987; Multon, Brown, & Lent, 1991; Pietsch, Walker, & Chapman, 2003). These studies indicate that examining the details of self-efficacy and its development may provide a mechanism for understanding why some students, particularly women, persist in the sciences while others do not.

2.2.2. Self-Efficacy and Women

The social cognitive theory of self-efficacy, provides a mechanism for understanding the information that women rely on when making decisions about their abilities to succeed in physics. Betz and Hackett (1981) published a seminal work on the relationship between self-efficacy and the career choices women and men make. They studied 200 college students asking about their confidence in ability to complete the educational requirements and job duties for 20 careers, split into those traditionally chosen by women (e.g. dental hygienist, elementary school teacher) and those traditionally chosen by men (e.g. accountant, engineer). Betz and Hackett found that women had significantly lower self-efficacy scores than men with regard to completing the educational requirements of many of the historically male-dominated occupations, with the greatest disparity appearing in engineering. Further, in the same study, Betz and Hackett found that these self-efficacy ratings were related to the type of occupations men and women considered as career options: gender entered as a significant predictor of the range of career options a student would consider, with men more likely to consider historically male-dominated occupations like mathematics and engineering. In another study, Matsui, Matsui, and Ohnishi (1990) used regression analyses to examine the contribution of the four sources to math self-efficacy. Their study showed that gender contributes significantly to the regression model and is not accounted for by any of the four sources of self-efficacy, suggesting that gender is a unique contributor to self-efficacy development in mathematics with men having higher self-efficacy than women. Physics shares many of the same educational requirements and job duties as both engineering and mathematics, and as such we consider these findings to be indicative of the relationship between self-efficacy and choice of physics as a career option.

Evidence furthering the argument for using in self-efficacy to understand differences in persistence for women and men comes from studies investigating the influence of gender on the four sources of self-efficacy beliefs. In a theoretical analysis, Hackett and Betz (1981) discussed Bandura’s theory of self-efficacy beliefs, in relation to how the four sources may be used to understand the self-efficacy differences between women and men in various fields. They suggested that women and men rely on different types of information in their daily lives, and that these differences most likely influence how each group considers its prospects as professionals. Building upon this work, Lent, Lopez, and Bieschke (1991) quantitatively explored the relationship between the four experiential sources and math self-efficacy. They found that gender differences in mathematics self-efficacy could be accounted for by the *mastery experience* score, suggesting that the development of self-efficacy differs for women and men. Similarly, Zeldin et al. (2000, 2008) examined the relationship between gender and sources of self-efficacy by completing two extensive qualitative studies with men and women who succeeded in STEM careers. Zeldin and Pajares (2000) found that women recalling experiences that impacted their decision to continue in a science or math career described events that were primarily identifiable as *vicarious learning* and *social persuasion* experiences. Subsequently, Zeldin, Britner, and Pajares (2008) found that men drew on personal *mastery experiences* when evaluating information that influenced their beliefs to pursue a career in the STEM fields. Looking at these three studies, we see that while the results do not all tell the same story, gender differences connect them together.

At this time, little research has been done investigating the development of student self-efficacy in physics, and what we have presents an inconsistent picture. Gungor, Eyilmaz, and Fakioglu (2007) found a negative relationship between physics self-efficacy and physics course achievement. Contradicting these results, Cavallo, Potter, and Rozman (2004) found that self-efficacy best predicted physics conceptual understanding as well as physics grade. Possibly accounting for these differences is the work of Fencl and Scheel (2005), who found that particular teaching techniques influence self-efficacy development in students in physics classrooms. Cavallo et al. also investigated the effect of gender, and found women had a lower self-efficacy than men throughout an introductory physics for biology major course. Shaw (2003) also found significant differences in self-efficacy between men and women in a physics-for-non-science-majors class. This small body of literature indicates there is little consensus about the role self-efficacy plays in physics at this point, but from the larger science self-efficacy literature it is clear that self-efficacy is an information rich and beneficial avenue of study for physics retention. Thus, I identify and address three research questions in this paper. (1) What role does self-efficacy play predicting success for all students in the first semester of the introductory physics class? (2) How can self-efficacy be used to understand the differences between women who are retained in the first semester introductory physics course and those who fail the same course? (3) By what means can self-efficacy better explain the disparity between the numbers of women and men who persist in physics?

2.3 Methods

Investigating how self-efficacy can be used to understand the lack of women in physics requires us to take a stance on what methods are and are not appropriate. The first consideration in this investigation is one of gender. As several researchers have noted, simply comparing female scores to male scores on various diagnostics, and looking at the differences between them, often leads researchers toward a framework where the underlying assumption is that women should be more like men (Baker, 2002) also often referred to as the deficit model (Baker & Leary, 1995; Gutiérrez, 2008; Nichols et al., 1998; Scantlebury & Baker, 2007). Thus, rather than characterizing differences between women and men, I choose a method that focuses on understanding the subtleties in the relationship between self-efficacy and the success of women and men separately. The second question then becomes one defining success. Since passing the introductory Physics with Calculus 1 course is a prerequisite to taking any other courses in physics, and thus in becoming a major, instead of focusing on grade received in the course, the method used in this paper attempts to predict the probability of a woman passing the introductory physics course. The variables of primarily interest for this prediction are the different sources of self-efficacy as well as other variables that have been previously linked to success in introductory physics such as incoming conceptual understanding of physics, and reformed courses. Thus, the method of analysis should create models that predict dichotomous outcomes (pass/fail) through a combination of continuous (conceptual understanding and self-efficacy) and categorical (course type) predictor variables. Additionally, the method should capitalize on the self-efficacy literature that has examined how the various sources of self-efficacy vary in relevance to gender. Thus, the chosen method utilizes prior knowledge in terms of the predictability of each variable.

My study implements a sequential logistic regression (SLR) method. Logistic regression, as an analysis technique, focuses on creating models that predict group membership from a set of previously determined predictor variables. In predicting group membership, the outcome variable to be studied is necessarily a dichotomous one, but logistic regression has few requirements for the predictor variables, thus allowing the contribution of both categorical and continuous variables to the model. The ultimate goal in logistic regression is to find the best combination of predictor variables that maximize the likelihood of correctly assigning a case to the observed group (Tabachnick & Fidell, 2007). Further, SLR allows for specification of the order with which the predictor variables enter the model, allowing the method to capitalize on the prior research on sources of self-efficacy. Finally, I have made an argument that in studying sources of self-efficacy it is necessary to attend to subtle differences that are covered up by focusing on gaps analyses. To this end, the method also needs to provide a mechanism for comparing the effect of one predictor variable to another. Sequential Logistic Regression also provides this mechanism through a comparison of coefficients in front of each variable in the model, allowing for a calculation of the size of the effect of each individual variable compared to the others.

2.3.1. Predictor Variables

Self-efficacy. Sources of Self-Efficacy in Science Courses - Physics (SOSESC-P) survey assesses the self-efficacy beliefs the students have towards their physics class in the beginning of the semester. The SOSESC-P was developed by Fencl and Scheel (2005) to probe the four sources of self-efficacy as described by Bandura (1997). The survey is a 33-item assessment that asks students to indicate how strongly they agree with statements about their ability in their physics class on a 5-point Likert scale (see Table 1 for example statements), and is disaggregated into four subscales by the four sources of self-efficacy: *mastery experiences* (*ME*), *vicarious learning* experiences (*VL*), *social persuasion experiences* (*SP*), and *physiological state* (*PS*). The ME subscale is measured on 10 items, the VL subscale on 7 item, the SP subscale on 7 items, and the PS subscale is measured on 9 items. Internal consistency reliability alpha coefficients range from .68 (SP) to .88 (PS) with the coefficient for the total scale at .94. In addition, all

SOSESC-P subscales and the total scale correlate significantly and positively with scores on the Self-Efficacy for Academic Milestones-Strength scale (Brown, Lent, & Larkin, 1986), a well-established measure of global self-efficacy in science and technology fields (Fencl & Scheel, 2005). The SOSESC-P is given to all introductory students in a PRE/POST format where the PRE portion is completed within the first 3 weeks of the start of classes. Similarly the POST portion is sent out 3 weeks before the end of finals week, and the survey is closed on the last day of finals week. My paper focuses only on the surveys given at the beginning of the semester because this is the only time all students, regardless of their success in the class, respond to the surveys. The SOSESC-P at FIU is administered online. Students receive e-mail requests for their input to help improve physics classes, which describe the survey as taking no more than 15 minutes to complete. The e-mail requests go to all students who are enrolled in the introductory a Physics with Calculus I classes by the third day of the semester. The e-mail requests occur three times during the first three weeks of the semester.

Table 1. Examples of SOSESC-P Items Used in PRE Survey

Item Number	Item Statement	Source of Self-Efficacy
1	I am capable of receiving good grades on my assignments in this class.	Mastery Experience
7	Listening to the instructor and other students in question-and-answer sessions makes me think that I cannot understand physics. **R**	Vicarious Learning
20	I get positive feedback about my ability to recall physics ideas.	Social Persuasion
13	I don't usually worry about my ability to solve physics problems.	Physiological State

Note. **R** = Reverse Scored

For the overall relationship between self-efficacy and success of a student I look at the overall average SOSESC-P score for each student. When disaggregating the data by gender, however, the average SOSESC-P is less appropriate, as shown by the work of Matsui, Matsui, and Ohnishi (1990), Lent, Lopez, and Bieschke (1991), Zeldin and Pajares (2000) and Zeldin et al. (2008), all of whom found that the impact of the of self-efficacy varied with the different source when looking at gender. Thus, the four self-efficacy sources are used when evaluating the data disaggregated by gender.

Force Concept Inventory. Though this paper primarily focuses on the usefulness of self-efficacy in predicting student success, it would be remiss to not take into consideration the results of other studies (Henderson, 2002) that show that pre-instruction conceptual understanding of physics is also a predictor of a student's success in the course. Thus, the Force Concept Inventory (FCI) is used as an indicator of conceptual understanding (Hestenes, et al., 1992). The FCI is a 30-item multiple-choice diagnostic that focuses on the conceptual understanding of Newtonian Mechanics, administered in a paper/pencil format. The FCI is also given in a PRE/POST format with the PRE portion being administered in all introductory Physics with Calculus I sections in the first week of classes. In order to have all variables taken from students in the same time period, and to enable predictions for success in one semester, this paper focuses only on the PRE FCI results.

Demographics. In addition to collecting SOSESC-P and FCI data, demographic data including gender and ethnicity was retrieved from the university database system. FIU collects self-reported gender and ethnicity data from incoming students. The students select from Asian, Black, Hispanic, Native American, White, or Not Reported for ethnicity, and from Female, Male, and Not Reported for gender. Florida International University is an urban research university enrolling 39,146 students in Fall 2008, of which nearly 60% are Hispanic and 57% are female (FIU Factbook, 2009). Students' final grade point in the Physics with Calculus I course was also retrieved from the university database system. Students who received an Incomplete were excluded from the data analysis as the official grade may still change.

Course type. All students included in this study are enrolled in an introductory Physics with Calculus I course. However, this Hispanic Serving Institution offers two types of courses in introductory physics: Modeling Instruction (MI) and traditional Lecture. Modeling Instruction is a reform effort that has had great success in improving student conceptual gains (Brewe et al., 2010), as well as improved retention rates (Brewe et al., 2010). The development of MI was guided by the Modeling Theory of Science (Hestenes, 1987), which focuses on the process of building, validating, and deploying scientific models. The implementation of MI is designed to give students an authentic scientific experience as well as to make the Nature of Science a coherent theme across content and pedagogy. Key elements to accomplishing these goals include (1) a focus on robust model development and deployment to describe physical phenomena (Brewe, 2008), (2) a collaborative, student-centered environment (Wells, Hestenes, & Swackhamer, 1995) as well as (3) large group consensus building discourse (Desbien, 2002). These elements are manifested in the MI classroom through a lecture-free environment, where students work in groups on inquiry labs and conceptual development activities. Also, portable whiteboards are central to the course, used both to encourage collaborative work within groups and as a presentation tool when groups report their findings to the class. The course does not follow a traditional organization of content, instead focusing on a small number of general models which can be applied to a variety of situations. There is also a great emphasis on conceptual understanding prior to moving forward with deploying models to arrive at numerical solutions. The MI course at FIU operates as a collaborative learning environment, with thirty students in a studio-format class with integrated lab and lecture (Brewe, 2008).

The Modeling Instruction approach strays significantly from a traditional Lecture approach. In contrast to a small number of models organizing the content, traditionally physics content is centered on a multitude of textbook chapters that often have little connection between them. Additionally, in traditional Lecture classes, there is a focus on problem solving which asks students to answer specific questions with well-defined numerical values without an emphasis on conceptual reasoning (Brewe, 2008). At FIU the traditional lecture-format classes are approximately 100 students in size, with little to no interaction between the professor and the students in the class. Each class is composed of a lecture section that meets 2 or 3 times per week for a total of 3 hours and 20 minutes, with a weekly 3-hour lab component.

It is already well documented that the MI course significantly improves the retention of all students in the course, including women (Brewe et al., 2010). However, the intentions in this research are not to compare instructional methods, but to understanding the influence of the sources of self-efficacy. Nonetheless, participants from two different course types are included in this study. To address this variability, Course Type is entered as a control variable in the model predicting success for all students, and the effect of adding self-efficacy in addition to Course Type is examined. The analyses looking at gender and the sources of self-efficacy uses an interaction variable between Course Type and the sources of self-efficacy (*ME*, *VL*, and *SP*). The interaction variable allows for the examination of how the Course Type and the sources of self-efficacy work together to predict the success of men and women.

Each of the predictor variables was assigned a dummy code. The initial variable coding (prior to converting to z-scores) can be seen in Table 2.

Table 2. All Students Logistic Model Specifications

Variables	Coding
Demographics	
Course Type	Modeling[a] = 1 (22.1%), lecture = 2 (77.9%)
Gender	Female[a] = 1 (39.7%), male = 2 (60.3%)
Continuous Variables	
Conceptual Understanding	Total FCI score (0-1) (M = .296, SD = .1339)
Self-efficacy	SOSESC-Avg score (0-5) (M = 3.629, SD = .5244)
	SOSESC-ME score (0-5) (M = 3.751, SD = .5623)
	SOSESC-SP score (0-5) (M = 3.676, SD = .5483)
	SOSESC-VL score (0-5) (M = 3.7117, SD = .5576)
Interaction Variables	
Course type and self-efficacy	Modeling*ME score (0-5) (M = .8878, SD = 1.687)
	Modeling*SP score (0-5) (M = .9041, SD = 1.716)
	Modeling*VL score (0-5) (M = .8887, SD = 1.6915)
	Lecture*ME score (0-5) (M = 2.8633, SD = 1.6032)
	Lecture*SP score (0-5) (M = 2.7723, SD = 1.5441)
	Lecture*VL score (0-5) (M = 2.8230, SD = 1.576)

[a]Reference Category

2.3.2. Outcome Variable

When researchers of self-efficacy have explored the predictiveness of this attitudinal variable, they typically describe the dependent variable as some form of success (Lent et. al., 1984, 1986, 1987; Hackett & Betz, 1989; Stipek, 1996). In some cases success is a description of academic interests, or perceived career skills (Lent et. al., 1986; Lapan, Shaughnessy, & Boggs, 1996). However, success is also often described as persistence through a course or task (Cervone & Peake, 1986; Lent, et al., 1984, 1986, 1987;) or through a career choice (Betz & Hackett, 1981; Zeldin et. al., 2008; Zeldin & Pajares, 2000). Following Fencl and Scheel's (2006) lead, the definition of success for the purposes of this study uses retention in the introductory physics course. Thus, a successful student earns a passing final grade in the class of a C- or better, and does not drop or withdraw from the course. Defined thus, the outcome variable is a dichotomous one, Pass or Fail. Successful students are able to continue in the physics sequence which should be viewed as the first level of success that a student achieves on the way to potentially choosing to become a physics major.

2.3.3. Analytic Approach

As discussed above, sequential logistic regression (SLR) builds models that predict a dichotomous outcome (pass/fail) through a combination of continuous (SOSESC-P score) and categorical (course type) variables, while capitalizing on prior research. Though SLR has few restrictions on the predictor variables, it is a necessary requirement that there is a relationship between the predictor variables and the outcome variable. First, correlations were computed to characterize the relationships between self-efficacy and final grade point (treated as a continuous variable) in introductory physics, and for the relationships between the four sources of self-efficacy. Next, comparative *t*-tests identified significant differences in self-efficacy between students who passed and students who failed in order to validate the choice of predictor variables. Finally, sequential logistic regression analyses were used to predict the outcome variable derived from the predictor variables.

The intention of the sequential logistic regression technique is to focus the interpretation of results on whether a particular variable significantly adds to the model's ability to predict the probability of the outcome when you have a theoretical ordering to the variables entered into the model (Tabachnick & Fidell, 2007). My study focuses on whether self-efficacy improves the predictive ability of the model when compared to other previously explored variables such as the FCI (Henderson, Heller, C., & Heller, K., 2002), and course type (Brewe et al., 2010). To this end the focus is both on how well the model (represented by *Model 1* below) predicts the observed outcomes as well as how the effect size (the odds ratio) of the coefficients of each variable (β_1 and β_2) in the model compare. Within each model maximum likelihood parameter estimates were used to determine the coefficients of the predictor variables.

The sequential logistic regression analysis and statistical software used in this study are thoroughly explained in Tabachnick and Fidell (2007) and Pallant (2007). Using SPSS 16.0 three different sets of sequential logistic regression analyses were computed. Within each analysis, several models were developed with different predictor variables. The analysis begins by creating a model using the predictor variables that literature predicts should have the greatest impact, and then sequentially eliminates and/or adds variables to compare this theoretical model to others. Goodness of fit with the observed data was obtained through evaluating the effect of omitting a predictor variable, that is comparing the predicative ability of *Model 1* (including the variable X_2) to *Model 2* (not including the variable X_2). If a significant difference between the predictive ability of *Model 1* and *Model 2* is found, then the data would suggest that variable X_2 is necessary in the model. The goal in sequential logistic regression analysis is to find the simplest model that is sufficient to predict the observed outcomes.

Model 1: $$\hat{Y}_i = \frac{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2}}{1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2}}$$ *Model 2:* $$\hat{Y}_i = \frac{e^{\beta_0 + \beta_1 X_1}}{1 + e^{\beta_0 + \beta_1 X_1}}$$

Categorical predictors were recoded into dummy variables before being entered into the SLR models. All measures were converted to *z*-scores in order to allow for the comparison of coefficients. Pearson's *r* was evaluated as a test of multicollinearity between the variables. Variables that were multicollinear were not included in the final models. The evaluation of all models was based upon an examination and interpretation of the chi-square goodness of fit for individual models and classification tables generated from the predictive model.

2.4 Participants

Participants are drawn from introductory Physics with Calculus I students at this Hispanic Serving Institution. The two-semester sequence is required for engineers, pre-health students, physics, and science majors alike. Historically, the first semester of the introductory physics class has a nearly 50% drop and/or fail rate at this institution. Therefore, it is an ideal setting to investigate the relationship between self-efficacy and students success in the course. In order to get a wide range of students who both pass and fail, this study draws on both the MI classes and the traditional Lecture classes. The data presented in this study are from students who were enrolled in physics Fall of 2008 and Spring of 2009. The students are all enrolled in one of two types of classes, either the Modeling class or the traditional lecture-lab class (referred to as Lecture).

A total of 352 of the 620 students enrolled in the introductory Physics with Calculus 1 course responded to the SOSESC-P survey via a total of six e-mail requests. Students who responded to the survey were representative of the larger sample in gender and ethnicity, however students who responded to the survey had an average grade point of 2.23 (C) and SD = 1.42 while students who did not respond had an average grade point of 1.57 (D+) and SD = 1.36. A *t*-test between the mean grade point of the students who responded and those who did not indicates a significant difference between the scores, $p<.0005$, $t(612) = 5.826$. However, the Cohen's $d = .42$ with a confidence interval ranging from .26 to .57 indicates that not responding to the survey has a small to at most medium effect on grade point. Of the 352 students who responded to the SOSESC-P survey, 8 people completed less than 80% of the items in the survey and were removed from the data set. Additionally, with the use of $p < .001$ criterion for Mahalanobis distance, 9 cases were found to be outliers in the sample, and thus were removed from the analysis. Additionally, gender was not reported by 4 students in the data set, and thus were removed from the analyses. The data from 331 students' responses to the SOSESC-P survey were used in this analysis. There were missing values for the FCI score for 16 students, thus the analysis including the FCI score uses 315 students. No significant differences between the sample population and the students removed from the data set were found. The demographic information for the total 331 students, including 198 male students and 133 female students, was collected via the University Database. The demographic and Modeling Instruction/Lecture distributions of all students in this study are provided in Figure 1, and are approximately representative of the student body at FIU.

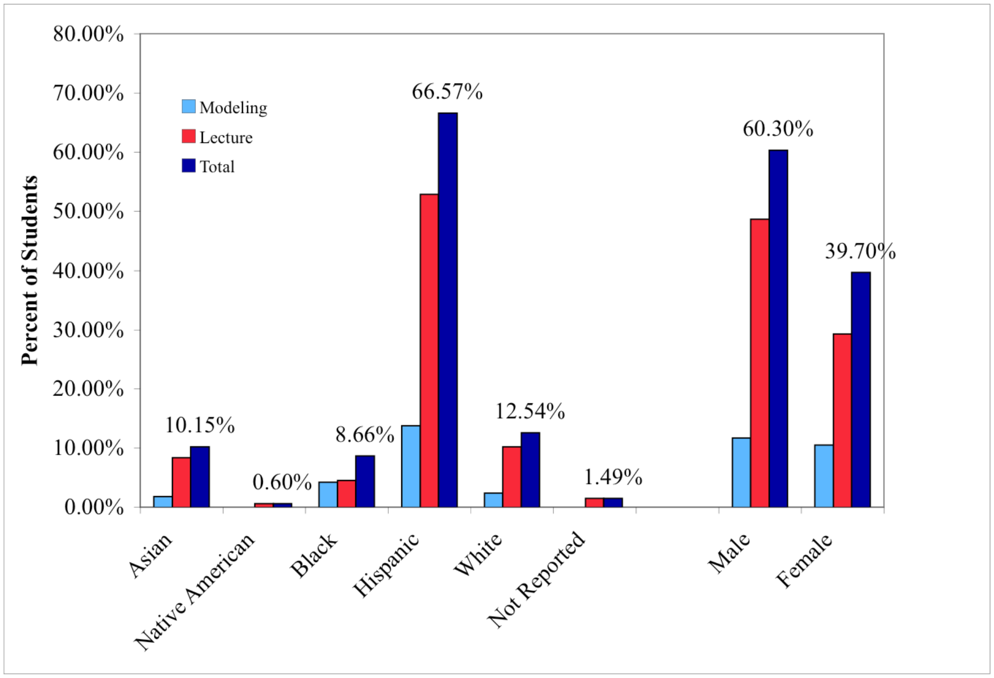

Figure 1. Demographics Introductory Physics with Calculus I students included in the data set.
Note: Numbers shown in the figure indicate the percentages of the total population

2.5 Results

2.5.1. Correlation

In order to address the applicability of using self-efficacy variables to predict success in the present study, two correlation tests on the PRE SOSESC-P data were completed. Table 3 shows results of correlation tests between PRE scores (average and the four sources) and the final grade point a student receives in the course. Results indicate a significant correlation between the average self-efficacy and grade point as well as for individual sources of self-efficacy and grade point for both men and women. This correlation, which accounts for 12% of the variance in the Male grade point and 9%

of the variance in the Female grade point, suggests that this choice of using passing as the dependent variable is a reasonable one.

Table 3. Correlations Between Sources of Self-Efficacy and Grade Point for Men and Women

	Average	ME	VP	VL	PS
			Grade Point		
Grade Point Men (n=200)	.345**	.328**	.282**	.289**	.316**
Grade Point Women (n=134)	.303**	.284**	.213**	.298**	0.282
			Sources of Self-Efficacy (n=334)		
ME	.939**	-	0.638**	0.786**	0.848**
VP	.784**	0.638**	-	0.678**	0.581**
VL	.890**	0.786**	0.678**	-	0.743**
PS	.920**	0.848**	0.581**	0.743**	-

**p<.001

The second correlation test was run between scores on individual sources of self-efficacy as measured by the SOSESC-P. As seen in Table 3, all of the sources are strongly correlated, suggesting the use of multivariate statistics. However, the *physiological state (PS)* source of self-efficacy is correlated at a very high (r = .848) level with the personal *mastery experiences (ME)* source. In order to avoid multicollinearity, which would violate the assumptions even for multivariate statistics, the *PS* is removed from the rest of the analysis allowing for the *ME* source to serve as the variable alone. This is consistent with the theoretical work of Bandura (1997) and Hackett (1981) who discussed *PS* as more of a mediating cofactor, amplifying or diminishing the effect of the other sources, than an independent factor.

2.5.2. *t*-Tests

I used *t*-tests to understand how self-efficacy could be used to understand the difference between students who are retained in the course and those who are not, separated by gender. The PRE SOSESC-P scores of the students who passed the introductory physics course are compared to the scores of those who failed, disaggregated by gender in order to examine the effect of the sources of self-efficacy. As seen in Table 4, men had a significant difference in every source of self-efficacy. The most significant effects were in the *social persuasion* (*SP*) experiences with a Cohen's *d* of .61, however, *mastery experiences* (*ME*) and *vicarious learning* (*VL*) also demonstrated large effects. Indicating that there are significant differences on all sub-scales of self-efficacy between men who passed the course and men who failed the course

Table 4. Comparison of PRE SOSESC-P Scores for Men Who Passed (n = 152) to Men Who Failed (n = 46)

		M	σ	t	Cohen's d	95% CI on Cohen's d
Average	Fail	-0.3546	1.00	-3.712	0.62***	[0.29, 0.96]
	Pass	0.2269	0.909			
ME	Fail	-0.3265	1.04	-3.429	0.58**	[0.24, 0.91]
	Pass	0.2088	0.893			
SP	Fail	-0.4688	1.01	-3.629	0.61***	[0.27, 0.94]
	Pass	0.1276	0.965			
VL	Fail	-0.363	0.991	-3.26	0.55**	[0.21, 0.88]
	Pass	0.1631	0.949			

Note. CI = Confidence Interval
**$p<.001$, ***$p<.0005$

As seen in Table 5, there are significant differences between women who passed the course and women who failed the course in every subscale except *social persuasion experiences (SP)*. The largest effect appears in the *mastery experiences* (*ME*) score with a Cohen's *d* of .45, with the *vicarious learning* (*VL*) score yielding an effect size of .38.

Table 5. Comparison of PRE SOSESC-P Scores for Women Who Passed (n=93) to Women Who Failed (n=40)

		M	σ	t	Cohen's d	95% CI on Cohen's d
Average	Fail	-0.4215	1.03	-2.196	0.42*	[0.04, 0.79]
	Pass	0.0085	1.04			
ME	Fail	-0.4375	1.04	-2.370	0.45*	[0.07, 0.82]
	Pass	0.0279	1.04			
SP	Fail	-0.1717	1.01	-1.654	0.31	[0.06, 0.68]
	Pass	0.1365	0.975			
VL	Fail	-0.3284	0.954	-2.026	0.38*	[0.01, 0.75]
	Pass	0.0597	1.04			

Note. CI = Confidence Interval
**p*<.05

From these two tables two conclusions are drawn: first, there are differences in self-efficacy between students who pass the course and those who fail the course; second, in accordance with literature, men and women appear to draw on different sources of self-efficacy. In all cases, the sources that are significantly different between men who pass and fail do not appear to be the same sources that are different for women. These results support the continued use of disaggregation by gender throughout the main analysis.

2.5.3. Sequential Logistic Regression Analyses

Sequential Logistic Regression analyses were ran to investigate the role self-efficacy plays in predicting the success of all students, both men and women. Further, the sources of self-efficacy are used in the SLR analyses in order to examine how self-efficacy might be used to explain the disparity between the numbers of women and men who persist in physics.

Predicting success of all students using self-efficacy. The first sequential logistic regression examined the influence of average incoming self-efficacy beliefs in physics on the probability of *all* students passing the introductory physics course. Table 6 displays the parameter estimates, significance values, the odds ratios, and the 95% confidence interval on the effect size for variables in the model for all students. Results indicate that adding conceptual understanding scores as well as self-efficacy belief scores to the control variable of course type significantly improved the model. Moreover, the overall model was found to be a significant fit to the observed data, $\chi^2(3, n = 315) = 28.002$, $p < .0001$, and yielded correct predictions for 78% of the sample. An examination of the odds ratios suggest that a student who is enrolled in the MI class is nearly twice as likely to pass the introductory physics class as a student enrolled in the Lecture course. Further, the odds ratio show that students with higher average self-efficacy scores were more likely to pass the introductory physics course. The significant addition of self-efficacy beliefs to the model for predicting all students passing, leads to the investigation of how the individual sources act for each gendered group.

Table 6. Logistic Regression Parameter Estimates and Model Evaluation - Predicting Passing of Introductory Physics

	Coefficient	Odds Ratio	95% CI on Odds Ratio
Course Type	-0.585	0.557	[.371, .836]
Continuous Variables			
Total FCI score	0.325	1.384	[.989, 1.935]
SOSESC-Avg score	0.362	1.437	[1.077, 1.916]
Model Evaluation			
Chi-Square	28.002***		
Percentage of correct classification (PCP)	72.42		

Note. All variables are standardized such that SD =1. CI = Confidence Interval.
***p<.0005

Predicting the success of male students using self-efficacy. The work of many researchers indicate that for male students *mastery experiences (ME*) are strongly related to self-efficacy, which is in turn strongly related to success (Britner & Pajares, 2006; Lent, et al., 1991; Lopez et al., 1997; Zeldin et. al, 2008). Thus, as Table 7 reflects, only the interaction variables between course type and *ME* source of self-efficacy was included in the base model, Male Model 1. Results indicate that this model was a better fit to the observed data than the constant-only model with $\chi^2(2, n = 198) = 22.775$, $p < .0005$, and correctly predicted 80.4% of the male cases. Further, as seen in Table 7, when other sources of self-efficacy beliefs were added, in alternating succession, there was no significant improvement to Male Model 1, which only included the *ME* source of self-efficacy beliefs.

In addition, examining the coefficients and corresponding odds ratios of the two interaction variables in Table 8 indicates a positive relationship between Course Type*ME and the probability of success for male students. The odds ratio for the Modeling*ME variable is 14.629, with a confidence interval consistently above 1.0, and similarly the odds ratio for the Lecture*ME variable is 4.565 with a confidence interval greater than 1.0. These effect sizes indicating having a high *ME* score results in a male student being more likely to pass the introductory physics course, regardless of in which course type they are enrolled. Further, as seen in Table 8, the model including the Modeling*ME and Lecture*ME variables correctly predicts 80.4% of the students who pass or fail the course.

Table 7. Logistic Regression Models: Evaluation of Male Model - Predicting Passing of Introductory Physics

	χ^2	df	-2LL	χ^2_{diff}	Δdf
	Male Specific Models				
Model 1 - ME Only	22.775***	2	191.884		
Model 2 - ME and VL	23.733***	4	190.926		
Difference between Model 2 & Model 1				0.958	2
Model 3 - ME and SP	24.39***	4	190.269		
Difference between Model 3 & Model 4				1.615	2
Model 4 - ME, VL, and SP	24.759***	6	189.901		
Difference between Model 4 & Model 1				1.983	4

***p< .0005

Table 8. Logistic Regression Models: Parameter Estimates of Female Model - Predicting Passing of Introductory Physics

	Coefficient	Odds Ratio	95% CI on Odds Ratio
	Male Model		
Interaction Variables			
Modeling*ME score	2.683	14.629	[3.370, 63.494]
Lecture*ME score	1.518	4.565	[1.508, 13.816]
Model Evaluation			
Chi-Square	22.775***		
Percentage of correct classification (PCP)	80.4		

Note. All variables are standardized such that SD =1. CI = Confidence Interval.
***p<.0005

Predicting the success of female students using self-efficacy. The qualitative results of Zeldin and Pajares (2000) indicate that for evaluating the success of female students we should consider the influence of both the *vicarious learning* (*VL*) source of self-efficacy as well as the *social persuasion* (*SP*) source of self-efficacy beliefs. Accordingly, Female Model 1 includes the interaction variables between course-type and both the *VL* and *SP* sources. As seen in Table 9, results indicate Female Model 1 is a better fit than the constant-only model to the observed data with $\chi^2(4, n = 133) = 14.247$, $p < .05$, and that Female Model 1 correctly predicts 69.9% of the female cases.

However, in Female Model 2 of Table 9, when excluding the *SP* from the model, there is no significant difference between Female Models 2 and 1. The lack of significant difference in the models suggests that the *SP* score is not a significant predictor for female students passing the introductory physics course. Moreover, in Female Model 3 when the *VL* source is eliminated, a significant difference between Female Models 3 and 1 appears. Combined with the previous result, the lack of significant difference between the models suggests the *VL* score is a significant predictor of female student success in introductory physics, while *SP* is not. Additionally, regardless of the other source variables present including the *ME* score, the Female Model shows no significant improvement to the fit.

A review of the parameter estimates for Female Model 1, in Table 10, including both *VL* and *SP* scores further supports the inclusion of the *VL* source of self-efficacy in the Female Model. However, when examining the odds ratios for the variables, the only effect size that shows a distinct positive relationship with predicting the passing of a female student is the interaction between *Modeling* and *VL* score. All the other confidence intervals on the odds ratios range from numbers less than one to numbers greater than one. Thus the only variable that can be noted to confidently predict the success of female students in the introductory physics course is the interaction variable *Modeling*VL*, with a student who has a high *VL* score being much more likely to pass the course than a student with a low *VL* score. Yet, with this model, 72.42% of the cases are correctly predicting as passing or failing the introductory physics course.

Table 9. Logistic Regression Models: Evaluation of Female Model - Predicting Passing of Introductory Physics

	χ^2	df	-2LL	χ^2_{diff}	Δdf
Female Specific Models					
Model 1 - VL and SP	14.247*	4	148.412		
Model 2 - VL Only	10.280*	2	152.379		
Difference between Model 2 & Model 1				3.967	2
Model 3 - SP Only	7.987*	2	154.672		
Difference between Model 3 & Model 1				6.26*	2
Model 4 - VL, SP, and ME	16.56*	6	146.099		
Difference between Model 4 & Model 1				2.313	2

*p< .05

Table 10. Logistic Regression Models: Parameter Estimates of Female Model - Predicting Passing of Introductory Physics

	Coefficient	Odds Ratio	95% CI on Odds Ratio
		Female Model	
Interaction Variables			
Modeling*SP score	-3.928	0.02	[0, 1.520]
Modeling*VL score	5.262	192.845	[1.885, 1972.3]
Lecture*SP score	0.26	1.296	[0.261, 6.42]
Lecture*VL score	0.225	1.253	[0.296, 5.307]
Model Evaluation			
Chi-Square	14.247*		
Percentage of correct classification (PCP)	72.42		

Note. All variables are standardized such that SD =1. CI = Confidence Interval.
*p<.05

2.5.4. Limitations

As with most studies, this one is not free of limitations. First, the sample size, when disaggregated by gender especially, is not large. All of the statistical assumptions were met with the data set included in the analysis, but it would be useful to have a larger data set in order to have more students falling into each category of the variables. Nonetheless, the conclusions drawn from this relatively small sample are useful and relevant for the science education community. Second, the logistic analysis itself has a limitation in that SPSS does not use a jackknifed approach in calculating the coefficients of the regression, instead the coefficients used to assign a case to a group are in part derived from that case. For this reason, I evaluated the effectiveness of the model generated from the Fall 2008 and Spring 2009 data further by looking at its ability to predict the passing of students from Fall 2009 semester. Last, there is always a question of selection effect when using data from any survey, and this study is not free from this problem. However, the models are sufficiently predictive of the relationship between self-efficacy and success that I proceed with the study while remaining aware of the limitations.

2.5.5. Predicting Fall 2009 Data

In order to account for the limitation in the logistic regression analysis of the SPSS analysis not using a jackknifed approach to develop and evaluate the models of predicting passing in the introductory physics course, the models created from the Fall 2008 and Spring 2009 data are used to predict the success of students enrolled in introductory Physics with Calculus I in Fall 2009. The results show that the prediction rates are consistent with the rates discussed in the model evaluation. The model for all students correctly classifies 86.2% of the data set. The male student model correctly classifies 83.6% of the cases. Finally, the female student model correctly classifies 80.8% of the cases. These data suggest that the evaluation of the model fits in Table 8 and Table 10 also hold for a distinct data set.

2.6 Discussion

2.6.1. Research Question 1

What role does self-efficacy play in predicting success for all?

As anticipated, the results from the sequential logistic regression analysis are consistent with previous work showing a positive relationship between self-efficacy and success in the classroom (Andrew, 1998; Lent, Brown, & Larkin, 1984, 1987; Multon, Brown, & Lent, 1991; Pietsch, Walker, & Chapman, 2003). Self-efficacy improves the model predicting success for all students in the course in addition to conceptual understanding and course type. Thus, the interest in exploring the predictive relationship differentiated by source is well supported. For physics specifically this is an important finding as it contradicts the results of Gungor, Eyilmaz, and Fakioglu (2007), and supports those of Cavallo, Potter, and Rozman (2004) by showing a positive relationship between physics self-efficacy and success in the course. Until there are more studies available for self-efficacy and physics, it is not possible to draw general conclusions about the effect, but as the results are consistent with studies in the larger science education body of literature, I hypothesize that the difference in the study done by Gungor et. al. (2007) is primarily one of population. Recall that in Gungor et. al.'s (2007) study, the course was compulsory for all university students in Ankara, while in this study students enrolled in the introductory Physics with Calculus I course by choice, admittedly primarily because is required for their major.

The results of the study must also be considered in the light that the students in our population are primarily Hispanic. In this respect, the majority of the students are part of the historically underrepresented population in physics, and showing that self-efficacy positively predicts the success of these students provides some subtle understanding of what impacts retention for this minority group. Specifically, students at FIU typically have a conceptual understanding of physics that is below that of the national average prior to taking a university physics course (Brewe, et al., 2010). So in relying on a purely conceptual understanding and course type model we would not expect these students to succeed at the same rates as majority students. However, showing that self-efficacy has a positive relationship with success in introductory physics provides a potential mechanism for influencing the success of both male and female Hispanic students.

2.6.2. Research Question 2

How can self-efficacy be used to understand the differences between women who are retained in the first semester introductory physics course and those who fail the same course?

Results indicate the *vicarious learning* source of self-efficacy is positively related to success of women in the introductory physics classroom, while neither the *mastery experience* source nor the *social persuasion* source is needed in the model. In many ways results from this study align with results from prior work in gender differences in self-efficacy (Hackett & Betz, 1989; Lent, Lopez, & Bieschke, 1991; Matsui, Matsui, & Ohnishi, 1990; Zeldin, Britner, & Pajares, 2008; Zeldin & Pajares, 2000). Findings from *t*-tests indicate there are differences in the sources of self-efficacy that are related to success for women and men. Most interesting is that while several investigators have found this to be the case quantitatively, they have not further investigated the result by looking for the subtle differences between men and women that may be overlooked by considering the data in a single large group. By considering the success of women and men separately and then building predictive models for each, the impact of each source of self-efficacy was examined as it was individually added to a predictive model of success for each group. This opens a window to identify a significant result for women that may have been overshadowed by a large effect in other areas for men.

Further, several studies have shown that self-efficacy predicts achievement (Andrew, 1998; Lent, Brown, & Larkin, 1984, 1987; Multon, Brown, & Lent, 1991; Pietsch, Walker, & Chapman, 2003), but if the interest primarily lies in addressing retention, then the distinction between A's and C's is less important than the difference between students who pass and fail the course. Thus the divisions in this paper are between success and failure. The results from the *t*-test analysis support this conclusion by showing there are significant differences in self-efficacy between students who pass the course and students who fail the course. For women the *t*-tests results show significant differences in every source with the *social persuasion* experiences source have the smallest relationship. However, the sequential logistic regression analysis has allowed for the understanding to move beyond simply concluding there are differences between those who pass and those who fail. Instead, results from this study show that *social persuasion* experiences do not add to the model predicting success for women. This result is not surprising when considered in light of research from Baker and Leary (1995) which showed that while girls in 2^{nd}, 8^{th}, and 11^{th} grade are aware of gender stereotypes, they do not agree that the stereotypes are true. The Baker and Leary (1995) study showed that girls in school receive mixed messages from society and the media, and thus it is not surprising that there is no clear effect of these messages on predicting retention in introductory physics.

On the other hand results from the *t*-test and sequential logistic regression analysis both support *vicarious learning* experiences having an effect on predicting the retention of women in physics. Again, research from Baker and Leary as well as studies from Roychoudhury et al. (1995), Arnold (1993), and Ferguson and Fraser (1998) support this result. Considering these studies it is easy to see how *vicarious learning* experiences would play a predictive role in retention in introductory physics. *Vicarious learning* experiences are those in which students see a person model a task they expect to perform, or where they compare their own achievement to another's achievement. These studies show that for women connections and relationships between themselves and other students, teachers, and role models are important to the career outcomes they expect to have as well as their attitudes about science. The importance of relationships for women shows up in the model with *vicarious learning* experiences having a strong relationship with the probability of retention for women in introductory physics.

However, the sequential logistic regression technique uncovers a further subtlety in the effect of *vicarious learning* experiences on predicting retention in introductory physics. The results show that only *vicarious learning* experiences * Modeling Instruction variable has a clear positive effect on the prediction of a female student passing the introductory physics course, while the contribution of *vicarious learning* experiences * Lecture variable is much smaller, and not clearly positive. Considering the differences between Modeling Instruction and traditional Lecture instruction in conjunction with literature on women in science helps to understand this result. Brotman and Moore (2007) discuss in their literature review on gender studies in science education how those investigating the impact of curriculum on women in sciences found that particular features have positive influences on all students, including women: curriculum focusing on integrating student experiences, classrooms that center on collaboration, environments providing opportunities for active participation, and assessing students in a variety of forms. Integrated into these features are opportunities for students to model tasks for one another and get direct comparison information from each other. These opportunities could be characterized as opportunities for *vicarious learning* experiences. Modeling Instruction aligns well with Brotman and Moore’s description of features: integrating collaborative group work, emphasizing student-student presentations throughout the course, as well as assessing students through a group exam, where the students work together and submit a single exam per group. Modeling Instruction not only provides opportunities for *vicarious learning* experiences, but also emphasizes the importance of them. Contrast this to the traditional Lecture environment where students are expected to develop knowledge individually, with this message reinforced by lecture classes where students are discouraged from talking with one another, homework assignments that do not encourage students to work together on solving problems, and course grades often being curved (increasing competition and discouraging collaboration). The main features of the Lecture classes provide little opportunity for the development of *vicarious learning* experiences. The stark differences between the two course types become obvious to students after the first couple days of class, and the emphasis, or lack thereof, on *vicarious learning* experiences may play a role in reducing the size of the contribution of this self-efficacy source to predicting success for women in the traditional Lecture course.

2.6.3. Research Question 3

> *By what means can self-efficacy better explain the disparity between the numbers of women and men who persist in physics?*

As is often done when trying to understand why men persist in the sciences while women do not, I start this discussion by analysis of comparisons. Many studies in physics education have shown conceptual understanding gaps between women and men, and in several studies they show that this gap widens over time. More recent discussions of gender in science education, such as an editorial from Baker (2002), have called for a discarding of this deficit model which presupposes that women should be scoring at the same rates as men. Thus, the analysis in this paper shies away from making direct comparisons between women and men, and focuses on developing individual models for men and women. With these two separate models it is more clear how self-efficacy influences the retention of women without being overshadowed by the influences for men. Coupling the results with literature on persistence in science for both genders we can better understand how self-efficacy works to explain the disparities in participation for men and women in science.

Results from this analysis indicate the success of men in introductory physics can be predicted by *mastery experiences* alone. It is possible to interpret this result through the lens of Bandura (1997) and justify this result through simply saying that we expect *mastery experiences* to be the most influential source of self-efficacy. However, if this simple answer was truly sufficient, then we should see similar results with women in introductory physics, but this result is not manifested in this study. Rather, it seems that the influential nature of the *mastery experience* source of self-efficacy should be interpreted in the light of the context of the classroom environment. *Mastery experiences* are defined by individual experiences with success and failure when performing tasks. In science, opportunities for these individual experiences abound. Sciences in university classrooms are typically taught in large lecture halls with little to no interaction expected of the students (Tobias, 1990), introductory level students are often expected to compete with one another on an individual basis rather than work together collaboratively (Seymour & Hewitt, 1997), and the traditional assessment techniques emphasize success at the individual level. Further, although Modeling Instruction uses many interactive teaching practices, assessment includes individual homework assignments, lab reports, and exams. Thus MI, like traditional instruction provides students ample opportunity to have *mastery experiences*. It is not surprising that differences between the predictive nature of *mastery experiences* does not vary with the two course types. Further, with all of these opportunities for individual success or failure in the traditional science classroom and the strong positive connection between the *mastery experience* score for male students and success in introductory physics, it should be no surprise that men have the experiences they need to increase their self-efficacy and thus continue to succeed in science classes.

On the other hand, multiple studies indicate that the experiences that would emphasize connection between students and build relationships are often missing from these traditional classrooms (Baker & Leary, 1995; Brotman & Moore, 2008; Danielsson & Linder, 2009; Lee & Burkam, 1996; Roychoudhury, et al., 1995; Scantlebury & Baker, 2007). The lack of opportunities that would encourage *vicarious learning* experiences, which would support the success of women in sciences, may be responsible for lack of women persisting in the sciences. Further, when the plethora of opportunities for *mastery experiences* is contrasted with the lack of opportunities for *vicarious learning* experiences, then a mechanism for how there exists such a large disparity between the numbers of men and women in physics emerges. While self-efficacy is related to success for all students, the experiences by which this self-efficacy impacts retention for men and women are starkly different, as different in fact as the opportunities for *mastery experiences* that abound in the classroom and the *vicarious learning* experiences that do not.

2.7 Implications

The results of this study center both on the subtleties in the predictive ability of the sources of self-efficacy for men and women in introductory physics as well as on the use of sequential logistic regression as a tool for uncovering these subtleties, and these results are important to both educators and researchers. First, these results suggest to educators that there is yet another reason to create classroom environments that are more collaborative in nature and provide students with opportunities to actively participate in activities. Not only do these environments help build conceptual understanding, but they also provide opportunities for *vicarious learning* experiences, and thus opportunities to affect the self-efficacy of female students in the classroom. With the double power of increasing conceptual understanding and increasing students' confidence in their own ability to do science, we have a potential mechanism for increasing retention and persistence of women in science.

Second, this study reveals implications for those researchers who are including self-efficacy in models to predict persistence and success. The results from this study suggest that these researchers should consider the more subtle differences in experiences that students have in developing their self-efficacy, as these experiences to not weigh equally for women as they do for men. To these researchers this works suggests building separate models for women and men and looking at the subtle differences in experiences that may be washed out in treating self-efficacy as a global measure of confidence in ability.

2.8 Conclusions

My study confirms previous findings in self-efficacy research for physics courses, but it also suggests that the differences between men and women in predicting success in introductory Physics with Calculus I may be subtler than originally supposed by researchers in self-efficacy. My paper has successfully explored the relationship between self-efficacy and student success in introductory physics, and has found self-efficacy to be a good predictor of success even after accounting for a reformed course and incoming conceptual understanding scores. Further, this study finds self-efficacy to be a rich dimension for understanding differences in retention for men and women. Results suggest that when splitting the groups apart we can see that in fact we can predict men's success in introductory physics by only looking at their *mastery experience* scores. However, for women the result is slightly more subtle than the result from the men. It appears that evaluating the *vicarious learning* score for women can predict their success, but the effect will be greater if they are enrolled in a reformed classroom such as Modeling Instruction. Further research in self-efficacy would investigate how *vicarious learning* can be impacted in the classroom, and if there is another layer to understanding what is happening for women in the traditional Lecture environment in physics. Additionally, it would be interesting to investigate whether these same trends hold up in other sciences in addition to physics, as well as how these subtle differences in sources of self-efficacy may influence the research linking *science identity* to persistence in science.

References (Chapter 2)

Andrew, S. (1998). Self-efficacy as a predictor of academic performance in science. *Journal of Advanced Nursing, 27*(3), 596-603. doi:10.1046/j.1365-2648.1998.00550.x

Arnold, K. D. (1993). Undergraduate aspirations and career outcomes of academically talented women: A discriminant analysis. *Roeper Review, 15*(3), 169-175.

Baker, D. (2002). Where is gender and equity in science education? *Journal of Research in Science Teaching, 39*(8), 659-663. doi: 10.1002/tea.10044

Baker, D., & Leary, R. (1995). Letting girls speak out about science. *Journal of Research in Science Teaching, 32*(1), 3-27. doi: 10.1002/tea.3660320104

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychological Review, 84(2), 191-215.

Bandura, A. (1997). In Brennan S. F., Hastings C. (Eds.), Self-efficacy: The exercise of control. New York, NY: W.H. Freeman and Company.

Betz, N. E., & Hackett, G. (1981). The relationship of career-related self-efficacy expectations to perceived career options in college women and men. Journal of Counseling Psychology*, 28*(5), 399-410.

Blue, J., & Heller, P. (2003). Using matched samples to look for sex differences. *AIP Conference Proceedings: 2003 Physics Education Research Conference, 720*(1) 45-48. doi:10.1063/1.1807250

Brewe, E. (2008). Modeling theory applied: Modeling instruction in introductory physics. American Journal of Physics*, 76*, 1155. doi:10.1119/1.2983148

Brewe, E., Sawtelle, V., Kramer, L., O'Brien, G., Rodriguez, I., and Pamelá, P. (2010). Toward equity through participation in Modeling Instruction in introductory university physics. Physical Review Special Topics-Physics Education Research, 6, 10106. doi:10.1103/PhysRevSTPER.6.010106

Brotman, J. S., & Moore, F. M. (2008). Girls and science: A review of four themes in the science education literature. *Journal of Research in Science Teaching, 45*(9), 971-1002. doi:10.1002/tea.20241

Brown, S. D., Lent, R. W., & Larkin, K. C. (1989). Self-efficacy as a moderator of scholastic aptitude-academic performance relationships. Journal of Vocational Behavior, 35(1), 64-75. doi:10.1016/0001-8791(89)90048-1

Carlone, H. B., Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. Journal of Research in Science Teaching,44(8), 1187-1218. doi:10.1002/tea.20237

Cavallo, A. M. L., Potter, W. H., & Rozman, M. (2004). Gender differences in learning constructs, shifts in learning constructs, and their relationship to course achievement in a structured inquiry, yearlong college physics course for life science majors. *School Science and Mathematics, 104*(6), 288-300. doi: 10.1111/j.1949-8594.2004.tb18000.x

Cervone, D., & Peake, P. K. (1986). Anchoring, efficacy, and action: The influence of judgmental heuristics on self-efficacy judgments and behavior. *Journal of Personality and Social Psychology, 50*(3), 492-501. doi: 10.1037/0022-3514.50.3.492

Dalgety, J., & Coll, R. K. (2006). Exploring first-year science students' chemistry self-efficacy. *International Journal of Science and Mathematics Education, 4*(1), 97-116. doi:10.1007/s10763-005-1080-3

Danielsson, A. T., & Linder, C. (2009). Learning in physics by doing laboratory work: Towards a new conceptual framework. *Gender and Education, 21*(2), 129-144. doi: 10.1080/09540250802213081

Desbien, D. M. (2002). *Modeling discourse management compared to other classroom management styles in university physics.* (Unpublished doctoral dissertation). Arizona State University, Arizona. (AAT 3054620)

Enochs, L. G., Scharmann, L. C., & Riggs, I. M. (1995). The relationship of pupil control to preservice elementary science teacher self-efficacy and outcome expectancy. *Science Education, 79*(1), 63-75. doi:10.1002/sce.3730790105

Fencl, H., & Scheel, K. (2005). Engaging students: and examination of the effects of teaching strategies on self-efficacy and course climate in a nonmajors physics course. Journal of College Science Teaching*, 35*(1), 20-24.

Fencl, H., & Scheel, K. R. (2006). Making sense of retention: An examination of undergraduate women's participation in physics courses. In J. M. Bystydzienski, & S. R. Bird (Eds.), Removing barriers: Women in academic science, technology, engineering, and mathematics (pp. 287-302). Bloomington, IN: Indiana University Press.

Ferguson, P. D., & Fraser, B. J. (1998). Student gender, school size and changing perceptions of science learning environments during the transition from primary to secondary school. *Research in Science Education, 28*(4), 387-397. doi: 0.1007/BF02461506

FIU Office of Planning and Institutional Effectiveness. (2009). *Enrollment Data.* Retrieved from http://w3.fiu.edu/irdata/portal/factbook.htm.

Gungor, A., Eryilmaz, A., & Fakioglu, T. (2007). The relationship of freshmen's physics achievement and their related affective characteristics. *Journal of Research in Science Teaching, 44*(8), 1036-1056. doi: 10.1002/tea.20200

Gutiérrez, R. (2008). A “gap-gazing” fetish in mathematics education? Problematizing research on the achievement gap. Journal of Research in Mathematics Education, 39(4), 357-364.

Hackett, G., & Betz, N. E. (1981). A self-efficacy approach to the career development of women. Journal of Vocational Behavior, 18(3), 326-339. doi:10.1016/0001-8791(81)90019-1

Hackett, G., & Betz, N. E. (1989). An exploration of the mathematics self-efficacy/mathematics performance correspondence. Journal for Research in Mathematics Education, 20(3), 261-273.

Hake, R. R. (2002). *Relationship of individual student normalized learning gains in mechanics with gender, high-school physics, and pretest scores on mathematics and spatial visualization*. Retrieved from http://physics.indiana.edu/~hake/PERC2002h-Hake.pdf

Hazari, Z., Sonnert, G., Sadler, P., & Shanahan, M.-C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. Journal of Research in Science Teaching. Advance online publication. doi:10.1002/tea.20363

Henderson, C., Heller, K., & Heller, P. (2002). Common concerns about the force concept inventory. The Physics Teacher, 40(9), 542-542.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *American Journal of Physics, 55*(5), 440-454. doi: 10.1119/1.15129

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. The Physics Teacher, 30(3), 141-158.

Ivie, R., Czujko, R., & Stowe, K. (2002). Women physicists speak: The 2001 international study of women in physics. *AIP Conference Proceedings:2002 Physics Education Research Conference, 628*(49).

Jones, M. G., Howe, A., & Rua, M. J. (2000). Gender differences in students' experiences, interests, and attitudes toward science and scientists. *Science Education, 84*(2), 180-192. doi: 10.1002/(SICI)1098-237X(200003)84:2<180::AID-SCE3>3.0.CO;2-X

Kost, L. E., Pollock, S. J., & Finkelstein, N. D. (2009). Characterizing the gender gap in introductory physics. *Physics Review Special Topic - Physics Education Research, 5*, 010101. doi:10.1103/PhysRevSTPER.5.010101

Lapan, R. T., Shaughnessy, P., & Boggs, K. (1996). Efficacy expectations and vocational interests as mediators between sex and choice of Math/Science college majors: A longitudinal study. *Journal of Vocational Behavior, 49*(3), 277-291. doi: 10.1006/jvbe.1996.0044

Lau, S., & Roeser, R. W. (2002). Cognitive abilities and motivational processes in high school students□ situational engagement and achievement in science. *Educational Assessment, 8*(2), 139-162.

Laws, P. W., Rosborough, P. J., & Poodry, F. J. (1999). Women's responses to an activity-based introductory physics program. American Journal of Physics, 67(7), S32. doi:10.1119/1.19077

Lee, O., & Luykx, A. (2007). Science education and student diversity: Race/Ethnicity, language, culture, and socioeconomic status. In S.K. Abell & N.G. Lederman (Eds.), *Handbook of research on science education* (2nd ed., pp. 171–197). Mahwah, NJ: Lawrence Erlbaum Associates.

Lee, V. E., & Burkam, D. T. (1996). Gender differences in middle grade science achievement: Subject domain, ability level, and course emphasis. *Science Education, 80*(6), 613-650. doi:10.1002/(SICI)1098-237X(199611)80:6<613::AID-SCE1>3.0.CO;2-M

Lent, R. W., & Brown, S. D. (2006). On conceptualizing and assessing social cognitive constructs in career research: A measurement guide. Journal of Career Assessment, 14(1), 12. doi:10.1177/1069072705281364

Lent, R. W., Brown, S. D., & Larkin, K. C. (1984). Relation of self-efficacy expectations to academic achievement and persistence. Journal of Counseling Psychology*, 31*(3), 356-362. doi:10.1037/0022-0167.31.3.356

Lent, R. W., Brown, S. D., & Larkin, K. C. (1986). Self-efficacy in the prediction of academic performance and perceived career options. Journal of Counseling Psychology, 33(3), 265-269. doi:10.1037/0022-0167.33.3.265

Lent, R. W., Brown, S. D., & Larkin, K. C. (1987). Comparison of three theoretically derived variables in predicting career and academic behavior: Self-efficacy, interest congruence, and consequence thinking. Journal of Counseling Psychology, 34(3), 293-298. doi:10.1037/0022-0167.34.3.293

Lent, R. W., Lopez, F. G., & Bieschke, K. J. (1991). Mathematics self-efficacy: Sources and relation to science-based career choice. Journal of Counseling Psychology, 38(4), 424-430. doi:10.1037/0022-0167.38.4.424

Lent, R. W., Lopez, F. G., Brown, S. D., & Gore, P. A., Jr. (1996). Latent structure of the sources of mathematics self-efficacy. Journal of Vocational Behavior, 49(3), 292-308. doi:10.1006/jvbe.1996.0045

Lorenzo, M., Crouch, C. H., & Mazur, E. (2006). Reducing the gender gap in the physics classroom. American Journal of Physics, 74(2), 118. doi:10.1119/1.2162549

Luzzo, D. A., Hasper, P., Albert, K. A., Bibby, M. A., & Martinelli Jr, E. A. (1999). Effects of self-efficacy-enhancing interventions on the math/science self-efficacy and career interests, goals, and actions of career undecided college students. *Journal of Counseling Psychology, 46*(2), 233-243.

Matsui, T., Matsui, K., & Ohnishi, R. (1990). Mechanism underlying math self-efficacy learning of college students. Journal of Vocational Behavior, 37, 225-238. doi:10.1016/0001-8791(90)90042-Z

McCullough, L. (2004). Gender, context and physics assessment [Special issue]. Journal of International Women's Studies, 5(4), 20–30.

Meece, J. L., & Jones, M. G. (1996). Gender differences in motivation and strategy use in science: Are girls rote learners? *Journal of Research in Science Teaching, 33*(4), 393-406. doi:10.1002/(SICI)1098-2736(199604)33:4<393::AID-TEA3>3.0.CO;2-N

Miyake, A., Kost-Smith, L. E., Finkelstein, N. D., Pollock, S. J., Cohen, G. L., & Ito, T. A. (2010). Reducing the gender achievement gap in college science: A classroom study of values affirmation. *Science, 330*(6008), 1234-1237. doi: 10.1126/science.1195996

Moe, K. O., & Zeiss, A. M. (1982). Measuring self-efficacy expectations for social skills: A methodological inquiry. Cognitive Therapy and Research, 6(2), 191-205. doi:10.1007/BF01183892

Multon, K. D., Brown, S. D., & Lent, R. W. (1991). Relation of self-efficacy beliefs to academic outcomes: A meta-analytic investigation. *Journal of Counseling Psychology, 38*(1), 30-38.

Mulvey, P.J., & Nicholson, S. (2010). Physics undergraduate enrollments and degrees (Report No. R-151.44). Retrieved from American Institute of Physics Statistical Research Center website: http://www.aip.org/statistics/trends/reports/EDphysund07.pdf

Nichols, S.E., Gilmer, P.J., Thompson, A.D., & Davis, N. (1998). Women in science: Expanding the vision. In B.J. Fraser, & K.G. Tobin (Eds.), *International handbook of science education* (pp. 967-978). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Pallant, J. (2007). SPSS survival manual: A step-by-step guide to data analysis using SPSS version 15 (3rd ed.) New York: Open University Press.

Pietsch, J., Walker, R., & Chapman, E. (2003). The relationship among self-concept, self-efficacy, and performance in mathematics during secondary school. *Journal of Educational Psychology, 95*(3), 589-603.

Pollock, S. J., Finkelstein, N. D., & Kost, L. E. (2007). Reducing the gender gap in the physics classroom: How sufficient is interactive engagement? Physical Review Special Topics-Physics Education Research, 3(1), 10107. doi: 10.1103/PhysRevSTPER.3.010107

Robertson, L. A. (2006). Why are there so few female physicists? The Physics Teacher, 44, 177-180.

Rosser, S. V. (2004). The science glass ceiling: Academic women scientists and the struggle to succeed. New York: Routledge.

Roychoudhury, A., Tippins, D. J., & Nichols, S. E. (1995). Gender-inclusive science teaching: A feminist-constructivist approach. *Journal of Research in Science Teaching, 32*(9), 897-924. doi:10.1002/tea.3660320904

Scantlebury, K., & Baker, D. (2007). Gender issues in science education research: Remembering where the difference lies. In S. K. Abell, & N. Lederman (Eds.), *Handbook of research on science education* (2nd ed., pp. 257-285) Mahwah, NJ: Lawrence Erlbaum Associates.

Schoon, K. J., & Boone, W. J. (1998). Self-efficacy and alternative conceptions of science of preservice elementary teachers. *Science Education, 82*(5), 553-568. doi:10.1002/(SICI)1098-237X(199809)82:5<553::AID-SCE2>3.0.CO;2-8

Seymour, E., & Hewitt, N. M. (1997). *Talking about leaving*. Boulder, Colorado: Westview Press.

Shaw, K. A. (2003). The development of a physics self-efficacy instrument for use in the *Review Special Topics Physics Education, 6*(020112) doi: 10.1103/PhysRevSTPER.6.020112

Stipek, D. J. (1996). Motivation and instruction. In D. C. Berliner, & R. C. Colfee (Eds.), *Handbook of educational psychology* (pp. 85-113). New York: MacMillan Library.

Tabachnick, B.G., & Fidell, L.S. (2007). Using multivariate statistics (5th ed.). Boston: Pearson.

Tobias, S. (1990). *They're not dumb, they're different: Stalking the second tier*. Tucson, AZ: Research Corporation.

Wells, M., Hestenes, D., & Swackhamer, G. (1995). A modeling method for high school physics instruction. *American Journal of Physics, 63*, 606. doi:10.1119/1.17849

Zeldin, A. L., Britner, S. L., & Pajares, F. (2008). A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. Journal of Research in Science Teaching, 45(9), 1036-1058. doi: 10.1002/tea.20195

Zeldin, A. L., & Pajares, F. (2000). Against the odds: Self-efficacy beliefs of women in mathematical, scientific, and technological careers. American Educational Research Journal, 37(1), 215. doi:10.3102/00028312037001215

Zohar, A., & Sela, D. (2003). Her physics, his physics: Gender issues in israeli advanced placement physics classes. *International Journal of Science Education, 25*(2), 245-268. doi:10.1080/09500690210126766

CHAPTER 3 IMPACTS OF INSTRUCTION ON SELF-EFFICACY

3.1 Abstract

Analysis of the impact of Modeling Instruction (MI) on the sources of self-efficacy for students in Introductory Physics 1 will be presented. Self-efficacy was measured through a quantitative diagnostic (SOSESC-P) developed by Fencl and Scheel [1] to investigate the impact of instruction on the sources of self-efficacy in all introductory physics classes. Both pre- semester data and post-semester data were collected, and the effect of the classroom was evaluated by analyzing the shift (Post-Pre). At Florida International University, a Hispanic-serving institution, this study finds traditional lecture classrooms negatively impact the self-efficacy of all students, while the MI courses had no impact on all students. Further, when disaggregating the data by gender and sources of self-efficacy, the study finds that Modeling Instruction positively impacted the *social persuasion* source of self-efficacy for women. This positive impact helps to explain high rates of retention for women in the MI classes.

3.2 Introduction

The confidence in one's ability to perform a task, defined to be one's self-efficacy [2], has been shown to predict a student's task persistence [3], performance in mathematics [4] , and persistence through technical fields [5]. At Florida International University (FIU), it has also been found that self-efficacy at the beginning of an introductory physics class predicts the likelihood of a student passing that same course [6]. Further, findings suggest that the sources one judges self-efficacy by change with gender.

Accordingly, efforts to increase the representation of women and historically underrepresented groups in pursuing physics majors would be greatly enhanced by understanding how physics classes affect the development of self-efficacy. To this end, this paper presents the analysis of changes in self-efficacy in the first semester introductory physics course at FIU. In order to explore both the impact of the class on the total self-efficacy, as well as how the self-efficacy develops for individuals this study presents data on aggregated students and self-efficacy, as well as data disaggregated by gender and sources of self-efficacy.

3.3 Background

At FIU many different students take introductory Physics with Calculus I. The first semester of the two- semester sequence is required for engineers, pre-health students, and science majors, as well as physics majors. Students at FIU have the option of enrolling in one of two types of introductory physics courses. The first is the traditional Lecture course, generally composed of nearly 100 students. This course meets 2 or 3 times a week for a total of 200 minutes for the lecture component with a once per week 3-hour lab component. The second option, the center of FIU's effort to diversify the physics major, is the Modeling Instruction (MI) course. The MI course operates as a collaborative learning environment with thirty students in a studio-format class that features integrated labs and lectures [7]. The course meets 3 times per week for approximately 2 hours, and focuses on developing and validating models through conceptual reasoning and problem solving.

The Modeling Instruction course has succeeded in improving conceptual understanding of physics, measured by the Force Concept Inventory (FCI) [8] when compared to the Lecture courses, and has also been shown to retain women and historically underrepresented groups at higher rates [9]. Nonetheless, when the FCI scores are disaggregated by gender Modeling Instruction maintains the conceptual understanding gap between men and women [9]. At FIU the odds of success, the ratio of students receiving a grade of C- or above to those receiving a grade of D+ or lower including Drops and Withdraws, in the Modeling Instruction classes are 6.73 times more likely than in the Lecture course despite the conceptual understanding gap. My study of self-efficacy at FIU is in part an effort to provide a mechanism for this phenomena.

In evaluating self-efficacy, Bandura emphasizes the need for specificity [10]. In other words, it would not be appropriate to ask students to rate their confidence in their ability to solve a difficult integral if one's goal is to evaluate self-efficacy of working in groups. Further, when analyzing how self-efficacy develops in an individual, it is necessary to consider the four experiential sources outlined by Bandura [10], *mastery experiences*, *vicarious learning experiences, social persuasion experiences, and physiological state*. In Bandura's work he theorized that *mastery experiences* would play the most important role in evaluating one's confidence to perform a task. However, recent work by Zeldin and Pajares [11] suggests men and women draw on different informational experiences. Women rely primarily on *vicarious learning* and *social persuasion* experiences [12] when evaluating their confidence in their scientific abilities, while men predominately draw on *mastery experiences* [11].

3.4 Methods

Appropriately keeping these recommendations in mind, this study evaluates self-efficacy and the experiential sources by which it develops through the Sources of Self-

Efficacy in Science Courses Survey – Physics (SOSESC-P) [1]. The 33-item survey is administered twice a semester as an online diagnostic. The SOSESC-P asks students to rate their confidence in ability on a 5-point Likert scale in various situations in the physics classroom. The survey can then be disaggregated into the four sources of self-efficacy, or reported as an average of all the sources for a total self-efficacy score. The first administration, labeled as PRE results, is given within the first 3 weeks of the introductory physics class beginning. The second, or POST, administration is given within the last 3 weeks of class and finals. Students receive an e-mail asking them to follow a link to a survey that takes roughly 20 minutes of their time.

3.5 Participants

Data for this study were collected from a total of 245 matched, PRE to POST, students in three semesters, Fall 2008, Spring 2009, and Fall 2009. Demographic and course enrollment data were collected from the university database. The data include responses from 70 Modeling Instruction students, 40 female and 30 male, as well as 175 Lecture students, 65 female and 110 male. Analyses were conducted using *t*-tests to compare POST scores to PRE scores for both the Modeling Instruction and the Lecture courses. Total SOSESC-P scores were compared POST to PRE for all students as an analysis of effect of course-type on all students' self-efficacy. Individual source scores were also compared POST to PRE, disaggregated by gender, to study the effect of the course on each individual source.

3.6 Results

3.6.1. Total Self-Efficacy Shifts for All Students

A distinct picture emerges when comparing overall average SOSESC-P scores for all students, see Table 11. For the Lecture students, there is a significant difference between the POST and the PRE self-efficacy score, with the POST-PRE difference yielding a negative result. Lecture student scores on the POST test were significantly lower than scores on the PRE test. The Cohen's *d* effect size of -.523 suggests a medium effect from the Lecture course, with a confidence interval around it suggesting a small to medium effect. On the other hand, the Modeling Instruction course shows no significant difference between the POST and PRE scores. The confidence interval around the Cohen's *d* effect size, crossing 0.0, supports the conclusion that the Modeling Instruction course has no effect on total self-efficacy.

Table 11. Comparison of Average PRE to POST Total SOSESC-P Results by Course Type

	Modeling Instruction (n = 70)	Lecture (n = 175)
Pre	3.838	3.565
Post	3.859	3.302
t	0.229	-6.923
p	0.819	<.0005***
Cohen's *d*	0.027	0.5233
95% CI (LL, UL)	(-0.207, 0.262)	(-0.6807, -0.365)

***p<.0005
CI = Confidence interval around Cohen's *d*, LL = Lower limit, UL = Upper limit

3.6.2. Shift in Self-Efficacy for Women

In order to evaluate the developmental impact of the introductory physics courses on the self-efficacy of students, the SOSESC-P scores are disaggregated by source.

Further, following the results of Zeldin and Pajares [11], the scores are also disaggregated by gender. The differences between POST and PRE for women and men were examined separately. The top half of Table 12 shows the results for each of these sources for the women in both the Modeling Instruction course (n = 40) and the Lecture course (n = 65).

Table 2 shows that for the Modeling Instruction (MI) courses, there is a significant difference between the POST and PRE scores only in *social persuasion* experiences source of self-efficacy. The positive shift paired with an effect size of .357 suggests a small and positive effect of MI on the *social persuasion* score of women in the course. Other sources for women in the MI course show no significant difference between the POST and PRE scores. Confidence intervals that all cross 0.0 for women in the Modeling Instruction course support the no significant effect conclusion.

The top half of Table 12 also shows the results from the Lecture course for women. These results indicate a significant negative difference between the POST and PRE scores in all of the sources of self-efficacy for women in the Lecture course. Further, the *mastery experience* and *vicarious learning* source of self-efficacy both show a medium negative effect from the Lecture course with a Cohen's *d* of -.522 and -.5489 respectively. Further contrasting with the MI result, the *social persuasion* source of self-efficacy in the Lecture course shows a significant negative effect, with a small effect size (Cohen's *d* = -.385).

3.6.3. Shift in Self-Efficacy by Sources for Men

In the bottom half of Table 12, the results from the SOSESC-P, POST and PRE are shown disaggregated by the four sources for men both in the Modeling Instruction (n

= 30) and Lecture (n = 110) courses. The trend from the female scores in the Modeling Instruction class is continued in this data set. No significant difference is evident in any of the four sources between the POST and PRE scores for male students in the MI course. Further, the confidence interval on all the effect sizes include or cross 0.0, supporting the claim that the MI course has no effect on the sources of self-efficacy scores for male students.

Looking at the results for the men in the Lecture Instruction course, there are significant differences between POST and PRE scores in every source of self-efficacy, as measured by the SOSESC-P. The *physiological state* source stands out as a medium effect with a Cohen's *d* of -0.526, while the *social persuasion* experiences source of self-efficacy shows the smallest effect with a Cohen's *d* of -0.249. The other two sources, *mastery experiences* and *vicarious learning*, both show a small negative effect from the Lecture course.

Table 12. Comparing PRE to POST SOSESC-P Results by Course Type, Disaggregated by Source and Gender

	Modeling Instruction				*Lecture Instruction*			
	Mastery Experience	Vicarious Learning	Social Persuasion	Physiological State	Mastery Experience	Vicarious Learning	Social Persuasion	Physiological State
Female	N = 40				N = 65			
Pre	3.78	3.79	3.86	3.52	3.598	3.56	3.567	3.117
Post	3.84	3.81	4.09	3.55	3.27	3.24	3.35	2.82
t	0.724	0.254	2.26	0.249	-4.211	-4.425	-3.104	-3.648
p	0.474	0.801	0.030*	0.805	<.0005***	<.0005***	.003**	.001**
Cohen's *d*	0.114	0.0401	0.357	0.0394	-0.522	-0.549	-0.3850	-0.0478
95% CI (LL, UL)	(-0.197, 0.425)	(-0.270, 0.350)	(0.0349, 0.675)	(-0.271, 0.349)	(-0.780, -0.261)	(-0.808, -0.286)	(-0.636, -0.132)	(-0.706, -0.195)
Male	N = 30				N = 110			
Pre	4.04	4.06	4.06	3.82	3.78	3.71	3.6	3.44
Post	3.91	4.00	4.11	3.74	3.52	3.49	3.45	3.11
t	-0.789	0.367	0.305	-0.443	-4.53	-3.66	-2.61	-5.51
p	0.437	0.716	0.762	0.661	<.0005***	<.0005***	.01*	<.0005***
Cohen's *d*	0.144	0.0670	0.0557	-0.0809	-0.432	-0.349	-0.249	-0.526
95% CI (LL, UL)	(-0.217, 0.513)	(-0.292, 0.425)	(-0.303, 0.413)	(-0.2783, 0.439)	(-0.627, -0.236)	(-0.541, -0.156)	(-0.438, -0.0582)	(-0.724, -0.325)

*p<.05, **p<.005, ***p<.0005
CI = Confidence interval on Cohen's d, LL = Lower limit, UL = Upper limit

3.7 Discussion

3.7.1. Effect of Course Type on Self-Efficacy

As described earlier in this paper, self-efficacy as a construct, has been linked to several positive factors for students such as persistence and performance [3-5]. Thus, as educators we would like to see our students positively impacted in the area of self-efficacy. However, how do we view a positive impact? In this study the Lecture course showed a negative effect on self-efficacy from the beginning of the semester to the end, while in the Modeling Instruction course there is no significant effect on total self-efficacy from PRE to POST. The results coincide with earlier results presented by Fencl and Scheel [13] suggesting that the traditional lecture classroom resulted in negative effects on self-efficacy while a class with a reformed pedagogy showed no significant impact on total self-efficacy. These combined results suggest that a positive effect on self-efficacy may actually reside in a no net change result.

When disaggregating the SOSESC-P scores by source type, is gained into how the two different classroom formats affect self-efficacy of students. The MI course implements many of the pedagogical techniques common to reformed classrooms in that it centers on group work and informal individualized interaction between student and instructor. The limitations of this study do not allow for making conclusive claims as to what features of the MI course impact self-efficacy, yet considering the key features of the course provides insight into how self-efficacy may develop within this course.

In contrast to the traditional Lecture classroom, the MI class provides frequent opportunities for *vicarious learning* experiences in the regular group work of the integrated lab activities. The course is also replete with formative assessment strategies as well as traditional homework and mid-term tests, thus providing further opportunities for positive *mastery experiences*. In other work, we have shown that the *physiological state* source is highly correlated with the *mastery experience* source [6], thus it is no surprise that when a student has positive *mastery experience* the *physiological state* also follows suit. Lastly, the interactions in the MI classroom between students and instructors provide for many positive *social persuasion* experiences, though it is interesting that even in the Lecture format course this source shows the least negative effect. This is consistent with Bandura's theory that the *social persuasion* source has the greatest impact on someone who already has a sense of self-efficacy.

3.7.2. Source Shifts in Self-Efficacy for Women

The sources of self-efficacy are important as they tell us about particular experience that affect the development of self-efficacy. Earlier studies show that men and women draw on different sources of self-efficacy with women relying on both the *vicarious learning* and *social persuasion* experiences [6, 12]. The data from my study suggest that the traditional Lecture classes negatively affect all of the sources for the students, regardless of gender. For women in particular, the Lecture class shows a medium negative effect on the *vicarious learning* source of self-efficacy, and a small negative effect on the *social persuasion* source. Contrasting with these results, the only positive effect seen in this study appears in the *social persuasion* experiences source of self-efficacy for women in the Modeling Instruction course. Combining these results with the understood relationship between self-efficacy and retention, this *social persuasion* source of self-efficacy may be part of the explanation for why women have a much higher odds of success in the Modeling Instruction course than they do in the Lecture format course.

References (Chapter 3)

[1] H. Fencl and K. Scheel, J. Col. Sci. Teach. **35**, 20 (2005).

[2] A. Bandura, Psychol. Rev. **84**, 191 (1977).

[3] D. Cervone and P. K. Peake, J. Pers. Soc. Psychol. **50**, 492 (1986).

[4] J. Pietsch, R. Walker, and E. Chapman, J. Educ. Psychol. **95**, 589 (2003).

[5] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. **31**, 356 (1984).

[6] V. Sawtelle, E. Brewe, and L. H. Kramer, Manuscript submitted for publication. (2010).

[7] E. Brewe, Am. J. Phys. **76**, 1155 (2008).

[8] D. Hestenes, M. Wells, and G. Swackhamer, Phys. Teach. **30**, 141 (1992).

[9] E. Brewe, V. Sawtelle, L. H. Kramer, G. E. O'Brien, I. Rodriguez, and P. Pamelá, Phys. Rev. ST PER **6**, 0106 (2010).

[10] A. Bandura, *Self-efficacy: The Exercise of Control*, edited by S. F. Brennan and C. Hastings (W.H. Freeman and Company, New York, NY, 1997).

[11] A. L. Zeldin, S. L. Britner, and F. Pajares, J. Res. Sci. Teach. **45**, 1036 (2008).

[12] A. L. Zeldin and F. Pajares, Am. Educ. Res. J. **37**, 215 (2000).

[13] H. Fencl and K. R. Scheel, PERC Conference Proceedings **720**, 173 (2003).

CHAPTER 4 IDENTIFYING OPPORTUNITIES TO IMPACT SELF-EFFICACY

4.1 Introduction

Recently the number of physics degrees awarded has fallen behind the number of degrees awarded in other science, math, and engineering fields [1]. As a result, research interests have focused on how students choose to major in various technical fields, and what the motivational factors are that impact their choice [2--7]. Since the 1980's an abundance of research has shown that science self-efficacy, or confidence in one's own ability to complete the actions necessary to perform a task [8], is related to success in particular fields [9--13], as well as a predictor of the career choice an individual will make [11,14--17]. A few researchers in physics education have also shown a link between physics self-efficacy and success [18--20]. Further, at Florida International University it has been found that Modeling Instruction has a positive impact on self-efficacy [21]. However, few researchers have focused on how self-efficacy develops and how it may be intentionally influenced.

Given that self-efficacy is such an important marker of these success factors, then it seems necessary that we as researchers fully explore its development and characterize the information that contributes to determining self-efficacy as well as consider interventions that influence the development of self-efficacy. In particular, the present research paper first completes a thorough literature review on what is already known about the development of self-efficacy. Next, the work proposes an alternative methodology for investigating how self-efficacy is formed with a focus on real-time events and how they unfold. Next, the paper demonstrates through a two-phase microanalysis of a problem-solving session that the proposed alternative method yields new information on the development of self-efficacy. Finally, a discussion is presented of how this methodology can be used in combination with more traditional methods to provide a different perspective on how self-efficacy develops in particular contexts.

4.2 Previous Research on the Development of Self-efficacy

Self-efficacy was first developed as an integral part of a theoretical framework attempting to explain how behavioral change takes place [22]. The concept of self-efficacy is defined as the confidence in one's own ability to perform a particular task. Originally, research into using the framework of self-efficacy focused on understanding behavior change of individuals with severe phobias [22,23]. Since then, however, self-efficacy has been shown to be a critical component of Social Cognitive Theory [8,24]. Social Cognitive Theory argues that humans use information gained from the world to make decisions about the actions they will take. Self-efficacy, as the confidence in one's own capability, determines the courses of an action an individual will take. People with high self-efficacy for a particular task will be more likely to choose a path that requires the performance of that task, to persevere in the task over long periods of time, and to persist in the face of difficulties. The utility in understanding the role of self-efficacy in academics then lies in the assumption that students with high academic self-efficacy are more likely to succeed in school, to choose career paths that require success in academia, and to choose majors that align with their self-beliefs about personal capabilities.

In particular, researchers have focused attention on science as an area that traditionally has low interest and persistence rates. Studies have shown that self-efficacy is able to predict a university student's persistence in science majors as well as science career choices [10,11,14,15,17]. Additionally, researchers have investigated how self-efficacy can predict achievement in science for high school students [25,26] and university students [9--13]. Florida International University, a Hispanic Serving Institution in the southeastern United States, has also found that a student's self-efficacy in physics at the beginning of an introductory physics course predicts the likelihood of a student passing that same course [27]. Further, in the reformed introductory physics classroom centered on Modeling Instruction, it is found that students' physics self-efficacy is positively impacted after one semester of the course [21].

4.2.1. Sources of Self-Efficacy

In order to understand how to positively impact self-efficacy, one must first understand how it is that self-efficacy develops over time. Upon initial reflection on the concept of confidence in one's own ability, it would seem reasonable to conclude that self-efficacy depends on skills already developed. Thus, we might expect that if the skills to complete a task are present, then the individual would necessarily have a high self-efficacy to execute the action. However, Schwartz and Gottman [28] have shown that even when people have the full set of skills and knowledge to perform a task, they can still feel incapable. Bandura [8] contended that confidence in one's ability does not rely directly on the number of skills, but on what an individual believes can be done in a particular circumstance. Bandura postulated that individuals derive self-efficacy information from experiences that focus on actually using these skills. Bandura [8] posited, and Lent et al. confirmed [29] that these experiential sources of information can be broken into four categories: personal *mastery experiences*, *vicarious learning* experiences, *social persuasion* experiences, and an individual's *physiological state*. Bandura [8] described each source of self-efficacy as serving a different role in the development of self-efficacy. However, he noted that disentangling the role each source plays may be difficult when examining the self-efficacy of an individual, as the development of self-efficacy through each source may influence the development of self-efficacy through the others.

While considerable research has been done investigating the relationship of self-efficacy to success, persistence, and career choice, fewer investigators have studied the development of self-efficacy. Within this smaller body of literature, much of the research focuses on confirming the relationship between the four experiential sources and self-efficacy itself [25,29--33]. The goal of this research is often to confirm or deny Bandura's hypothesis that personal accomplishments in the form of *mastery experiences* play the primary role in an individual evaluating his/her capability. Researchers have also tried to determine if factors such as gender or particular tasks change the types of information drawn upon in judging self-efficacy [25,32,33]. Regardless of the focus, the majority of the research takes place by developing quantitative surveys that use researcher-derived experiences as stand-ins for the theoretically posited sources of self-efficacy [29,32--36]. The limitation with these methods is that it does not leave room for researchers to uncover additional factors that people may draw on when judging their capability. With this in mind, a few researchers have turned to qualitative data collection methods [29,30,37--40]. These methods, ranging from factor listing to semi-structured interviews, have revealed interesting ideas about self-efficacy and how the dependence on each of the individual sources varies across individuals, particularly for those of different genders. The following sections outline the research that has been done on the contribution of each experiential source to self-efficacy, as well as propose an alternative way of investigating the development of self-efficacy.

Mastery Experiences

Bandura [8] described enactive *mastery experiences* as being the primary indicator of confidence in capability. He theorized that these *mastery experiences*, experiences with previous personal attainments or failures in a task similar to the one at hand, had the most influence over an individual's confidence in ability because they provide authentic evidence as to whether the individual can do what it takes to be successful at the task. Many researchers studying the influence of *mastery experiences* have found evidence to support Bandura's conjecture that these experiences have the greatest sway for determining self-efficacy [41]. In her quantitative 2008 study of the self-efficacy of high school students in various science courses [25], Britner found *mastery experiences* played a critical role in determining self-efficacy. In Britner's study students were asked to answer a survey about their confidence to succeed in their science course as well as to rate the types of experiences they had in the past. Britner found *mastery experiences* were the only significant predictor of self-efficacy across all the fields of science for boys. Similarly, Matsui, Matsui, and Ohnishi [33] found past grades in mathematics course (which they described as a *mastery experience*) account for the largest variance in predicting the mathematics self-efficacy of Japanese students in high-school math classes.

Results from some qualitative studies also support the claim that *mastery experiences* are the most influential. In 1996 Lent et al. completed a study asking university students to first rate their confidence in their ability to pass a particular math class with a grade of B or higher [31]. Once this task was completed, the researchers asked the students to reflect on the information they used to rate their capability. The students were then asked to make a list up to 10 of these factors, from which they then identified the most influential factors. Upon analysis, Lent et al. found that experiences that could be classified as *mastery experiences* were predominate in the lists the students made. Further, in 2006 Hutchison et al. completed a study using similar methodology, again employing the factor-listing technique [30]. This time the course in question was an introductory engineering course, and all of the students in the study were currently enrolled in the course at the time of the study. Hutchison et al. also found that most of the factors that first-year engineering students listed as influencing their confidence in ability to succeed in an introductory engineering course could be categorized as *mastery experiences*.

In interview studies, the influence of *mastery experiences* became more mixed. In 2008 Hutchison et al. did a follow-up interview study with students enrolled in the same introductory engineering course [37]. The students were interviewed twice: once three weeks into the course, and a second time halfway through the course. In this follow-up study the researchers found that before any of the students had the course, their self-efficacy for success in the engineering course came almost entirely from *mastery experiences*. However, when students were interviewed 3 months into the semester, students described performance comparisons (*vicarious learning*) in abundance rather than performance experiences. In addition, Zeldin, Britner, and Pajares [40] completed another interview qualitative study, with findings indicating the influence of *mastery experience* depends on gender. In this work, the researchers interviewed women and men who have successful careers in science or mathematics. The researchers asked the participants questions designed to elicit thoughts about significant events that had and influence on them throughout their career. The results suggested that *mastery experiences* are the primary influences on the male participants, but not the most influential for the women in the study.

Overall, these studies suggest that when evaluating experiences quantitatively *mastery experiences* appear as a dominant predictor of overall self-efficacy. However, results have also demonstrated that when completing in-depth interviews, the impact of *mastery experiences* is less clear. *Mastery experiences* have been shown to be an influential source for students when recalling their experiences on paper, but when the students are interviewed the connection between self-efficacy and personal *mastery experiences* becomes less clear.

Vicarious Learning

The distinguishing feature of *vicarious learning* experiences is the observation of another person performing a task. *Vicarious learning* experiences can take two distinct forms: (1) modeling, when an individual sees a person similar to oneself perform a task [8] and (2) performance comparison, when an individual's focus is on determining how much better or worse one's own performance was compared to another's [37]. Usher and Pajares [41] point out that performance comparisons are particularly relevant in academic settings, as in most academic settings there is not an absolute measure of what success means. As a result, students judge their performance based on what others are doing. In terms of modeling experiences, the impact of models on self-efficacy depends on a few factors: how similar the individual sees the model to be like themselves, whether the model demonstrates a coping mechanism (struggling through problems) or a mastery model (successful completion of the task), and how competent the model is at performing the task [8,41].

In Bandura's theory of the influence of *vicarious learning* on self-efficacy, he contended that peers would have a greater influence on self-efficacy than adults for students [8]. However, few researchers have investigated this claim. One study investigating the independent factors that contribute to self-efficacy did consider the effect of splitting peer modeling from adult modeling [31]. Ref. 31 found that peer modeling appeared as a distinct factor in the factor analysis, and had a stronger relationship to the measured self-efficacy than did the adult modeling factor. Possibly a result of not distinguishing between the type of model are the low to modest reliability coefficients for the *vicarious learning* factor on several quantitative self-efficacy surveys [32--36].

The difficulty in measuring the *vicarious learning* source of self-efficacy may also be reflected in conflicting results from various studies on its predictive relationship with self-efficacy. Several quantitative survey design studies have identified *vicarious learning* experiences as the source that is least likely to predict self-efficacy [32,34,42]. In factor listing tasks, *vicarious learning* experiences were not referenced as a primary influence on determining individual's self-efficacy either [30,31]. On the other hand, studies focusing on non-majority students, such as students of South Asian descent [43] and African American middle school students [36], have found that *vicarious learning* experiences have a significant relationship with self-efficacy.

Additionally, in qualitative interview investigations, *vicarious learning* experiences seem to play an important role in distinguishing the development of self-efficacy for men and women. Investigating the development of self-efficacy for women in science and mathematics careers, Zeldin et al. [39] found that women primarily described interactions with others and often referenced the vicarious experiences these interactions provided when reflecting on how their confidence in capability developed over time. Additionally, in an interview study of the longitudinal development of self-efficacy in an introductory engineering class, Hutchison et al. [37] found that a distinguishing factor between men and women was the type of *vicarious experience* they recalled throughout the engineering class. These researchers found that men were likely to describe comparison or modeling experiences that were positive for building confidence, while women were more likely to describe experience that would have a negative influence on their confidence in capability.

In general, *vicarious learning* experiences appear difficult to measure yielding low reliability measurements and conflicting results in the source's predictive ability for self-efficacy. However, the results of some studies suggest that *vicarious learning* experiences may play a key role in differentiating the development of self-efficacy for students of various ethnic backgrounds, or when investigating the self-efficacy of men and women.

Social Persuasion

The primary definition of *social persuasion* experiences focuses on the messages an individual receives from others about their ability to perform a task. When Bandura [8] defined *social persuasion* experiences as a source of self-efficacy, he primarily focused on the experience of receiving evaluative feedback on a performance. Bandura discussed how individuals cannot rely solely on themselves to provide self-evaluation because it requires knowledge of which they might only have a limited amount. Instead, individuals rely on others deemed credible to provide evaluative feedback needed to judge performance capabilities. However, Bandura also discussed the idea that these messages are not always conveyed verbally. Rather, social evaluations of competence are often conveyed indirectly and may be communicated through social practices or indirect commentary. In their review of the sources of self-efficacy literature, Usher and Pajares [41] noted that many studies have investigated the *social persuasion* influence by focusing primarily on the encouraging messages students perceive from their peers, teachers, and parents. While these investigations are in line with Bandura's theory of how *social persuasion* experiences work to influence self-efficacy, it is notable that most researchers do not examine the messages sent to students from the larger culture, or considering how those messages might be conveyed without verbal encouragement.

In both the qualitative and quantitative literature, *social persuasion* experiences take a prominent role when comparing the development of self-efficacy beliefs for women and men. In an investigation by Zeldin et al. [39] into the development of self-efficacy for women in science and math careers, it was found that women more often recalled *social persuasion* experiences than they did *mastery experiences*. On the other hand, when the men spoke of *social persuasion* experiences it was in a passive manner, which contrasted starkly with the discussions from women in the previous study [40].

Results from other studies, both quantitative and qualitative, are mixed in supporting the findings of Zeldin et al. In Britner's 2008 study on the self-efficacy of high school students in various science classes [25], she found that *social persuasion* had the strongest effect on self-efficacy for girls in life sciences classes. However, she also found that the *social persuasion* source did not significantly predict the self-efficacy of girls in physical science classes. Additionally, in factor listing studies, neither men nor women listed *social persuasion* experiences as a primary influence in determining self-efficacy in engineering or math [30,31].

In addition to gender differences, the contribution of *social persuasion* experiences to self-efficacy may vary with cultural background. In a 2004 study, the mathematics self-efficacy beliefs of South Asian immigrant students derived more from *vicarious learning* influences and *social persuasion* experiences than did their White counter-parts [43]. Similarly, Usher and Pajares [36] found that for African American students *social persuasion* experiences accounted for the most variance in predicting their academic self-efficacy, while all four of the sources predicted the self-efficacy of White students.

Overall, a similar picture develops for the literature on *social persuasion* experiences as the one that was discussed for *vicarious learning* experiences. The *social persuasion* source of self-efficacy appears to often be inadequately probed in quantitative surveys as they do not address the indirect messages communicated by society. Futher, when studies consider different ethnic groups

Physiological State

Bandura [8] defined the *physiological state* source of self-efficacy as the somatic information individuals rely on when evaluating capability to perform a task. Individuals may interpret stress in a particular situation as an indicator that they are not capable, or a feeling of strength or stamina as an indicator of capability. In the literature, however, researchers have primarily focused on the effect of anxiety on self-efficacy with little attention to the more positive physiological states that may influence an individual's confidence in capability [41]. Even within this limited investigation, results measuring the relationship between anxiety state and self-efficacy have been mixed [41]. On the other hand, math anxiety has been found to reliably predict math self-efficacy [32,44], but not with as strong a prediction as the other three sources of self-efficacy. These varying results may be because anxiety is not truly a complete representation of the *physiological state* source of self-efficacy as it does not address any of the positive impacts this source may have on self-efficacy.

Qualitative research has addressed the *physiological state* source minimally. Both the factor listing tasks from Lent et al. [31] and Hutchison et al. [30] mentioned findings related to the *physiological state*, but in neither study did it take a prominent role in determining self-efficacy. The lack of *physiological state* in the qualitative literature may be a result of the difficulty in assessing this source. Bandura [8] contended that activities are often surrounded by a number of situational variables that may carry emotional information. Further, each of these emotional reactions carry different messages to different individuals. For example, a particular individual may interpret nervousness before a giving a public presentation as a sign of incompetence, but another may identify it as a sign of the adrenaline rush necessary to project their voice loudly and clearly. Couple this with the idea that pre-existing self-efficacy beliefs will affect how an individual processes somatic information, and we see that the *physiological state* may be viewed as a co-effect with the other three sources of self-efficacy [8,45]. Viewing the *physiological state* as a co-effect implies that disentangling the effect of *physiological state* from the other source variables may be incredibly difficult, particularly in qualitative work. As such, this work does not consider *physiological state* in this analysis, and instead focuses the attention on interpreting and understanding the other three sources of self-efficacy.

4.2.2. An Alternative Approach to Investigating the Sources of Self-Efficacy

While the researchers have used a variety of methods to understand the development of self-efficacy, many of the studies into the sources of self-efficacy have approached the question from the same direction. The majority of studies have used quantitative surveys in which researchers create items that they believe will elicit the correct type of capability information to be classified under one of the four sources of self-efficacy. Qualitative studies that have been completed focus on interviewing participants about their beliefs in their capabilities and then coding their responses by the types of experiences they describe, with a middle ground factor-listing type of research filling the continuum between quantitative and qualitative studies. While these methods are varied, there is a common element to all of these studies: they focus on eliciting past experiences from the participants.

These studies, both quantitative and qualitative, have been quite revealing in how the hypothesized sources influence confidence in capability, as well as revealing additional factors and subtle differences between the theoretically derived sources of self-efficacy. However, in relying on participants to reflect on their past, the studies ask participants to both accurately recall the information they used to influence their decision about capability, and to accurately represent all the details of an event that influenced the judgment of their capability. In Bandura's *The Exercise of Control* [8] he noted that the way an individual recalls an event is most likely not an accurate reproduction of the event. He went on to say that what is important in developing self-efficacy then, is not the event itself but the way an individual interprets it. This results in a difficulty, however, for those who would like to influence the way self-efficacy develops. How can we create experiences that will increase self-efficacy if we cannot be sure of the way the event will be interpreted? What happens that makes us recall an event in a particular way? What things are individuals in these interview studies not mentioning when they weigh information to determine their capability? And how do these things that are not mentioned or not recalled influence the way our self-efficacy develops?

It is with these types of questions in mind that this research has taken a different perspective on characterizing the way self-efficacy develops. I approach the question of how self-efficacy develops by attempting to characterize experiences that have the potential to influence reasoning about one's capability in the future. In doing so, I do not claim that these events will indeed be recalled in future analyses of self-efficacy, but in focusing on these experiences which present the opportunity to build self-efficacy it may be possible to see how particular actions or events influence self-efficacy development in a way that would not be possible if the only data asked people to reflect on their past. To this end, this paper begins the discussion of characterizing experiences as *self-efficacy opportunities* (*SEO*s). The primary focus of my paper is on a moment-by-moment analysis and connecting these detailed descriptions to the particular types of experiences that students think about when judging their self-efficacy. My paper also demonstrates that some of these *SEO*s are indeed taken up and directly influence confidence in ability.

4.3 Statement of the Problem

The goal of this study is to understand how self-efficacy could be influenced as the event itself is unfolding. A working assumption underlying the analysis is that self-efficacy is influenced through the theoretically posited sources of self-efficacy. My research question focuses on how these experiences take shape as events unfold. To this end, the analysis uses a microanalytic lens [46] which focuses attention on the *how* of human interaction [47].

4.4 Methods

The study evolves in two parts. The first uses a microanalysis of three participants participating in a problem-solving session for evidence of *self-efficacy opportunities*. In order to verify that these opportunities do indeed represent events that have the potential to influence self-efficacy, this phase is followed with a set of individual post-hoc interviews with the participants. The post-hoc interviews are analyzed for evidence that the *SEO*s identified in the problem solving session are sometimes taken up and do influence self-efficacy.

4.4.1. Modeling Instruction Classroom as a Context for this Study

Underlying all portions of this study is the classroom, and the norms of the environment, of which all the participants are members. The Physics Education Research Group at Florida International University has focused on increasing the number of historically underrepresented groups in physics primarily through reforming the introductory physics classroom to feature Modeling Instruction. Modeling Instruction (MI) is a reform effort that has had great success in improving student conceptual gains [48], as measured by the Force Concept Inventory [49], as well as improved retention rates [48] and attitudes toward learning physics [50]. The development of MI was guided by the Modeling Theory of Science [51], which focuses on the process of building, validating, and deploying scientific models. The implementation of MI is designed to give students an authentic scientific experience as well as to make the Nature of Science a coherent theme across content and pedagogy. Key elements to accomplishing these goals include (1) a focus on robust model development and deployment to describe physical phenomena [52], (2) a collaborative, student-centered environment [53] as well as (3) large group consensus building discourse [54].

At FIU, MI operates in a collaborative environment with thirty students in a studio-format class with integrated lab and lecture. Inquiry labs and activities are focused on conceptual reasoning and modeling physical phenomena. Students working in small groups on these activities are the primary way models in the classroom are built, validated, and deployed. This paper focuses on one element of the MI classroom design: describing physical phenomena through the use of student-developed and -deployed models. Previous research at this institution has shown that MI improves self-efficacy over the course of a semester [21]. One motivation for this study is to understand the mechanism for how MI has impacted self-efficacy over time. With this motivation in mind, this research does not only focus on how participants reconstruct events that occur in the MI classroom. Rather, this study attempts to characterize the ways that self-efficacy could potentially be impacted over time during an activity that mimics those that occur in the MI classroom.

4.4.2. Participants

Participants in this study were three students from a MI class, Lisa, Gina, and Jessica, who were familiar with working with one another. All three of the participants were women enrolled in the same introductory physics MI class during the semester they participated in the problem-solving portion of this study. Further, all three are part of a small cohort within the university system, are pre-medical biology majors, and are in their junior year of college. Lisa and Gina are identical twin sisters, and Jessica is both a friend and a colleague. Neither Lisa nor Gina had any experience with physics prior to the MI course. Jessica had taken physics in high school, but in later interviews expressed the view that she still valued what she had learned in the MI course. All three women volunteered for the study and were paid for their time.

4.4.3. Data Collection & Analytic Framework

As described above, the data collection in this study took place in two distinct parts. The first, the problem-solving session, was a videotaped session in which the three participants worked together to model a physical phenomenon. The second, the post-hoc sessions, were three individual sessions in which the original problem-solving participants viewed themselves on video and expressed feelings/opinions about how the events influenced their self-efficacy.

Problem Solving Session

Lisa, Gina, and Jessica participated in four problem-solving sessions over the course of the first four weeks of the semester (one each week of the semester). The first session was designed simply to get the students comfortable with solving a problem together in front of a camera. I was present during each session and clarified the activities that took place during session. The session took place in a room adjacent to the participants' classroom that had a large table and set of whiteboards and were videotaped. The three women were given a problem, chosen by their instructor to be similar to those given in their MI classroom, and were instructed to spend 45 minutes working on the task. The problem was designed to be just at the edge of what the students had learned in class. In this way, the expectation of the researchers was that the students would need to work together to move forward in the problem solving process. Additionally, the participants were asked to talk aloud as they worked on the problem, focusing on why and what they were doing. This paper includes the microanalysis of a 1-minute segment from the second session, which focused on modeling a 1-dimensional, constant acceleration situation as seen below.

> A car, initially at rest, accelerates toward the west at 2.0 m/s^2. At the same time that the car starts moving, a truck, 350m west of the car and moving at 16 m/s toward the east, starts to slow down, accelerating at 1.0 m/s^2. The car and truck pass safely. *[55]*

The expected outcome of modeling this physical situation for the students at this point in the semester includes creating and reasoning with internally coherent position-time, velocity-time, and acceleration-time graphs as well as a pictorial representation, motion map, and possibly an algebraic solution for the time and position when the car and truck would meet. An example of an acceptable solution is shown in Figure 2. The participants were familiar with this type of question from the MI classroom as well as the expected outcomes.

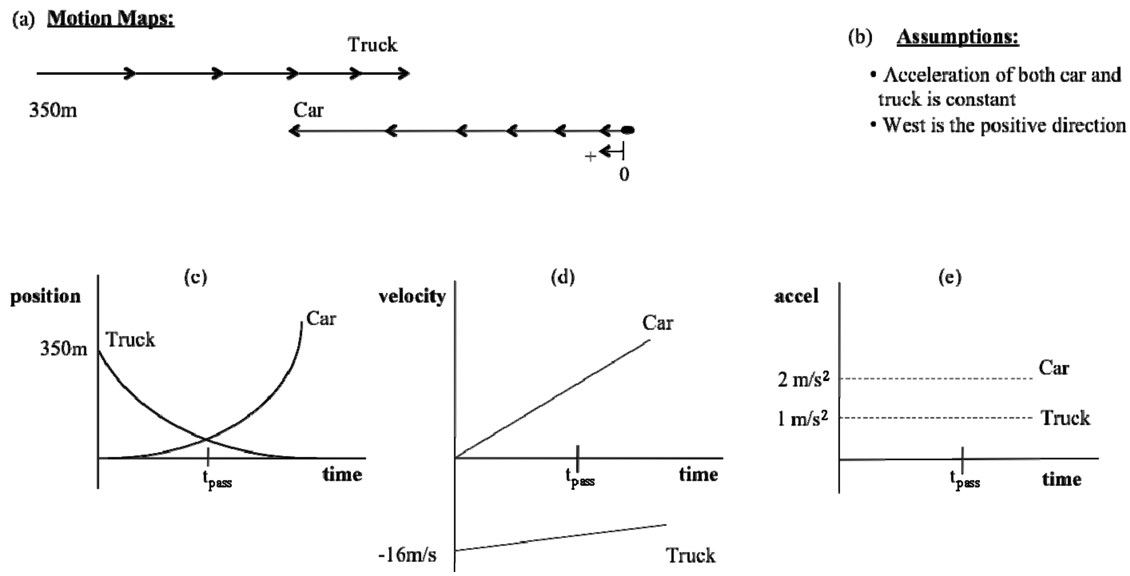

Figure 2. An example of an acceptable solution to the problem-solving session scenario for the students at this point in the semester.
(a) Represents motion maps for the car and truck with a defined frame of reference, (b) lists the important assumptions, (c-e) depicts a coherent set of position-time, velocity-time, and acceleration-time graphs.

The video was analyzed using Erickson's microanalysis of interaction [46], which aims to describe processes that produce particular outcomes in great detail. In this case the goal is to describe events that unfold in an instance of physics problem solving through the lens of self-efficacy building experiences. To this end a particular section of the problem-solving session was chosen based upon the boundaries that defined the process the participants were going through. In this case a clip was chosen that focused on the students building and reasoning with an internally consistent set of position-time, velocity-time, and acceleration-time graphs. Next, the event was carefully transcribed, taking great care to note particular non-verbal actions that may contribute to our theoretical frame [47] of self-efficacy building experiences such as head nods and gaze direction. Finally, the transcript and video were analyzed by looking for short snippets of interactions that could be classified as *self-efficacy opportunities*. This stage required several viewings of the event in order to deeply describe and identify opportunities for the various sources of self-efficacy to be taken up for each of the three participants involved.

Post-Hoc Interviews

Lisa, Gina, and Jessica each participated in individual post-hoc interviews one year after the problem-solving sessions were completed. The interviews were designed to focus around the videos taken of the problem-solving session. After a few questions regarding their overall experience in the Modeling Instruction physics class each participant individually watched the same segment, 8.5 minutes long, of the second problem solving session chosen and transcribed by the first author. Each participant was asked if there was any portion of the segment that stood out to her. After the participant identified segments were discussed, the interviewer went through six pre-chosen 30-second clips that had been chosen prior to the interview. I present the micoranalysis of one episode that consists of two of these sequential clips in this paper. Two of the clips not presented here, as well as the additional video, were included at the beginning of the interview in order to achieve a comfort level from the participants, as embarrassment is a top concern when dealing with video recordings [46]. Each of the clips was chosen because they had been previously described by researchers as demonstrating at least one *self-efficacy opportunity* for each of the participants. In the interview each participant was asked to watch each clip twice. In the first viewing they were asked to focus on themselves and to share thoughts about what they were feeling and how the event impacted them. In the second viewing the participant was asked to focus on the other two women in the problem-solving session and again to discuss what they saw happening and how it may have impacted each of the women in the room.

These post-hoc interviews were analyzed for evidence that the participant's self-efficacy was impacted by the event in the problem-solving session. As such, the videos were analyzed for mention of changing confidence in capabilities, then the corresponding moment was cross-referenced with the originally analyzed problem solving session.

4.4.4. Reliability and Validity

To maintain reliability of the interpretations in the data analysis several measures of validity were performed during the data collection and analysis. First, the data collection and design of the problem solving sessions were discussed and designed among several researchers. Additionally, researcher reflexivity [56] was established through the use of a researcher reflection notebook, a method used for researchers to monitor their subjectivity during data collection and analysis. Reliability during the microanalytic process was achieved through a combination of peer debriefing [56], where periodic reviews of the study with individuals familiar with the process occurred at regular intervals, and through triangulation of both the microanalysis of the problem-solving process and the post-hoc interviews. Additionally, though only 1 minute of data analysis are presented in this paper, an additional 30 minutes of data were microanalyzed in an effort to be sure that the episode was representative of the interactions seen in the problem-solving sessions [46].

4.5 Results & Discussion

As described in the Methods section, I approached this work through a two-phase analysis process: a microanalysis characterizing *self-efficacy opportunities* in a short segment of video from the problem-solving sessions, followed by an analysis of the portion of the post-hoc interviews that focused on the same segment of video for evidence of the *SEO*s being taken up by the participants. I present the results of this analysis in a similar manner within each source of self-efficacy, first identifying *SEO*s and following with a discussion of evidence from post-hoc interviews that the *SEO*s are taken up.

The 1-minute segment microanalyzed in this work is a portion of the larger problem solving session and focuses on Lisa, Gina, and Jessica attempting to build and reason with internally coherent position-time, velocity-time, and acceleration-time kinematic graphs to model the situation. This segment was chosen because there is abundant activity and interaction between the students. Just before this episode the three women have decided that they can assume the acceleration of both the car and truck is constant, which is appropriate in this situation. In the transcript below they focus on trying to represent the velocity of the car. The episode ends with the women trying to transition to finding the change in position by using the velocity graph they just drew. In the following transcript, gestures, actions, and interruptions are enclosed in curly brackets.

Segment 1

Gina: And then this {the velocity time curve} is positive. The velocity would somehow be this? {draws a curved line} Agree? {looking at Jessica}

Jessica: {shakes her head} It would be more like this. {mimes drawing a straight line} That would be position.

Gina: It would be oh, a line. Yeah, a line. So it could be like this…or like this, right?{drawing 2 lines on the board, and looking at Jessica}

Gina: That's the problem we had in class. {turning towards Lisa}

Jessica: {laughter}

Gina: It could be either one.

Lisa: No, because if velocity is increasing

Jessica: {interrupting Lisa} The slopes change.

Lisa: Yeah, the slope of this is negative, so this {*a-t*} would be negative. So it has to be above. {Gina watches}

Gina: But it would be like…this, no, we're assuming {draws the positive slope line}

Gina: And then to get the…to get the…this area, what was the equation?

Lisa: It's a triangle.

Gina: Yeah, but it's change in...p…

Jessica: {interrupting Gina} Velocity?

Lisa: {at the same time as Jessica} She's confusing herself.

Gina: What's the equation for displacement?

In this episode we see the participants working to draw the shape of the velocity-time curve. They begin with Gina proposing a curved line for the v-t graph (lines 1 – 4), and then two possible straight lines with different slopes (8 – 11). Jessica and Lisa work together checking that the proposed velocity-time graph is consistent with the horizontal line they have drawn for the acceleration-time graph (lines 5 – 21). At the end of the episode we see Gina attempting to use the velocity information to find displacement using the area under the velocity-time graph (lines 26 – 34).

The descriptive analysis of this segment is presented by the various *self-efficacy opportunities* (*SEO*s) that are present during the problem-solving session, followed by evidence from the post-hoc interviews demonstrated the *SEO*s being taken up and impacting the self-efficacy of the students. The analysis is broken into the three types of opportunities for self-efficacy (*VLO*, *SPO*, *MEO*), and thus the analysis of some of the same events appears under multiple headings. By combining the well-researched characterizations of self-efficacy experiences from the past-tense perspective with characterizations of *opportunities* for self-efficacy experiences in the present-tense situation, the goal is to provide researchers/educators a way to construct events that can be hypothesized to impact self-efficacy.

4.5.1. Vicarious Learning Opportunities

Identifying and Characterizing Vicarious Learning Opportunities

Vicarious learning opportunities (*VLO*s) can be difficult to identify as the analysis requires evidence that one individual is performing a task and that another person is paying attention to the performance of that task. The process of a model performing a task and an observer attuned to the model's task performance requires the analysis of two distinct roles: the modeler and the observer. In characterizing *VLO*s, then, some evidence is required that the observer is actually cognizant of the performance. The evidence of the observer paying attention to the task may come from several verbal or non-verbal signals such as a verbal affirmation, or a gesture like a nod or shake of the head. When we turn to analyzing Segment 1 for evidence of *VLO*s, we see several unfolding in the first several lines.

Segment 1a

Gina: And then this {the velocity time curve} is positive. The velocity would somehow be this? {draws a curved line} Agree? {looking at Jessica}

Jessica: {shakes her head} It would be more like this. {mimes drawing a straight line} That would be position.

Gina: It would be oh, a line. Yeah, a line. So it could be like this…or like this, right?{drawing 2 lines on the board, and looking at Jessica}

Gina: That's the problem we had in class. {turning towards Lisa}

Jessica: {laughter}

Gina: It could be either one.

Lisa: No, because if velocity is increasing

Jessica: {interrupting Lisa} The slopes change.

Lisa: Yeah, the slope of this is negative, so this {*a-t*} would be negative. So it has to be above. {Gina watches}

Gina: But it would be like…this, no, we're assuming {draws the positive slope line}

In lines 1 - 7 we see a *VLO* when Gina, in the role of model, attempts to draw a curved line for the velocity-time graph. As she draws the line, she turns to look at Jessica, who serves as the observer, and Jessica responds by shaking her head, indicating no. In this interaction we see Gina first performing the task of drawing a representation of the velocity from the acceleration graph, and we see evidence that Jessica is watching this task performed through her disagreement with what Gina drew. Gina's demonstration of the task provides a *vicarious learning opportunity* for Jessica that she may reflect upon later to influence her self-efficacy for representing velocity-time graphs.

Immediately following this interaction Gina again turns to the board, as the model in the situation, and draws two straight lines for the velocity graph, one above the x-axis with a positive slope, and the other below the x-axis with a negative slope (lines 10 – 11). In the next couple of lines we see she looks both at Jessica and turns toward Lisa. They both respond, indicating observation of the task, to her drawing by talking about the slope of the line (17 – 23). Again, this provides a *vicarious learning opportunity* for Lisa and Jessica as they may recall Gina's uncertainty about which line is correct, and later judge their own competence accordingly.

Alternatively, we may also view this entire sequence as a *VLO* for Gina. In lines 21 – 23 Lisa, serving as the model, reasons aloud why only one of the lines could be correct based on the information about the slope of the line. Gina, the observer in this case, watches as Lisa reasons through this, and then draws the positive sloped line (25 – 26), indicating that she was paying attention to the reasoning Lisa provided. Later, Gina may recall how Lisa reasoned through this problem in determining her confidence in her ability to draw a similar velocity-time graph.

References to Vicarious Learning Opportunities are Abundant

As described in the Methods section, the post-hoc interviews begin by watching an 8-minute episode that included Segment 1 presented above. Then each participant was asked if anything stood out to her during the episode. Of the three participants, only Lisa commented on specifics of the session without prompting. After Lisa watches the full episode the interviewer asks if she has any initial impressions. First she outlines the role she plays as "getting everyone started." She immediately follows this statement, however with one about the influence of the problem-solving events on her self-efficacy. Lisa says,

> I think Gina, every time we [Lisa and Jessica] would say something, she was kind of like, 'Wait, wait, wait. Maybe it could be this, but.' So everyone was just getting confused, 'cause just when you thought you had the right thing, then someone is contradicting you, and so you think, 'Maybe it's not right.'

The interviewer, noting the influence of the problem solving events on Lisa's confidence in her ability asks if there was a particular instance that made Lisa feel this way. She identifies lines 8 – 11 of Segment 1a where Gina attempts to draw a velocity-time graph, and draws two possible lines, one with a positive slope and the other with a negative slope. Originally, this clip was described as representing a *vicarious learning opportunity* for both Lisa and Jessica in terms of impacting their self-efficacy to draw a similar velocity-time graph.

When watching this clip, Lisa breaks in at line 11 and says, "So she draws it up, and then she does it, 'maybe it could be this way.'" After Lisa reasons aloud why the two lines could not both be right, the interviewer again asks her about what made her unsure in this clip. Lisa responds with,

> Yeah, the fact that she even brought it up. So I thought, 'Wait, maybe.' I didn't just want to say, 'No, no, no, it's not that way.' Because it was a new concept. So I just wanted to make sure beforehand. And the fact that Jessica agreed, just like, 'OK, maybe it is this way.'

In Lisa's response to this clip, two things become apparent. First, her confidence in her capability to draw a velocity-time graph was shaken by these events in the problem solving session. Secondly, the moment she identifies becoming unsure is focused on the performance of Gina. It is the vicarious learning experience of watching Gina draw the velocity-time graph that impacted Lisa's self-efficacy, which directly connects to the *VLO* identified earlier.

Further evidence of a *vicarious learning opportunity* being taken up in this series of events comes from Jessica. In this case, she did not specifically identify Segment 1, but it was instead shown to her as part of the six clips shown to all of the participants. Immediately after watching the clip (ending at line 15) where Gina proposed that either of the two lines could be correct for the velocity-time graph, Jessica responds to the video with, "There I was doubting myself. In terms of umm the slope." The interviewer asks if Jessica's laughter at this point in the episode (line 14) holds any meaning, and Jessica answers,

> I don't think it means anything really. It's just sort of like, I'm just thinking. And, you know, they brought something up, and I'm like, 'OK, I don't know what to say.' I'm not really sure of myself at the moment.

Again, in Jessica's response to this video, we see a discussion of her confidence in capability as a direct result of Gina bringing up the possibility of the two lines for the velocity-time graph. Combining Jessica and Lisa's post-hoc interview comments then, we see that in this case the *vicarious learning opportunities* identified for Lisa and Jessica in the problem-solving session were indeed taken up and impacted their self-efficacy through the vicarious learning experience they gained from Gina.

4.5.2. Social Persuasion Opportunities

Identifying and Characterizing Social Persuasion Opportunities

As described in the literature review, researchers have had mixed results in investigating *social persuasion* experiences. I theorize that this may be because the messages one receives about performance and capability are often difficult to articulate. In evaluating this episode, we find that the events that can be characterized as *social persuasion opportunities (SPO)* are often subtle interactions that take an in-depth analysis to uncover. To this end, the gestures notated in brackets in the transcript become critically important in the discussion of *SPO*s.

The current analysis returns to Segment 1 described in the previous section, which depicts Gina drawing a velocity-time for the car. This time the analysis focuses particularly on the actions that take place within this series of events, described within the curly brackets in the transcript.

Segment 1a

Gina: And then this {the velocity time curve} is positive. The velocity would somehow be this? {draws a curved line} Agree? {looking at Jessica}

Jessica: {shakes her head} It would be more like this. {mimes drawing a straight line} That would be position.

Gina: It would be oh, a line. Yeah, a line. So it could be like this…or like this, right?{drawing 2 lines on the board, and looking at Jessica}

Gina: That's the problem we had in class. {turning towards Lisa}

Jessica: {laughter}

Gina: It could be either one.

Lisa: No, because if velocity is increasing

Jessica: {interrupting Lisa} The slopes change.

Lisa: Yeah, the slope of this is negative, so this {*a-t*} would be negative. So it has to be above. {Gina watches}

Gina: But it would be like…this, no, we're assuming {draws the positive slope line}

A sequence of two events provides an opportunity for social persuasion for Jessica. Gina has the marker in her hand, and draws two different representations for the velocity on the velocity-time graph (lines 1 – 11). During this process, she pauses twice and turns her head to look at Jessica and ask, “Agree?” (line 3 – 4), and “Right?” (line 10). In turning to look at Jessica for evaluation of her performance, Gina communicates to Jessica that she believes in Jessica’s ability to evaluate the answer she has proposed. As such, Jessica may interpret this experience and evaluate her confidence in capability using this information, thus classifying the experience as a *SPO* for Jessica.

When this segment extends a *social persuasion opportunity* unfolds for Gina in the final lines of the segment.

Segment 1b

Gina: But it would be like…this, no, we’re assuming {draws the positive slope line}

Gina: And then to get the…to get the…this area, what was the equation?

Lisa: It’s a triangle.

Gina: Yeah, but it’s change in...p…

Jessica: {interrupting Gina} Velocity?

Lisa: {at the same time as Jessica} She’s confusing herself.

Gina: What’s the equation for displacement?

In lines 26 – 27 Gina makes a bid for a shift in activity by asking what the equation for the area under the curve of the velocity-time graph is. Lisa responds in line 28 with, “It’s a triangle.” And Gina reassures her that she knows and starts to ask a slightly different question in line 29. Jessica attempts to finish the sentence, but Lisa breaks in with, “She’s confusing herself,” in lines 31 – 32 in reference to Gina’s request. Gina appears frustrated and restates her question in lines 33 – 34 as, “What’s the equation for displacement?” The interruption and commentary from Lisa on Gina’s not yet completed work represents an opportunity for a social persuasion experience for Gina. She may remember Lisa's interruption later and judge her ability to write the expression for displacement from an area under the curve based upon this experience.

Students Articulate the Impact of Social Persuasion Opportunities

Gina's post-hoc interview did not yield much information about self-efficacy until she finished watching the entire episode and all six pre-selected clips. At this point in the interview, the interviewer told Gina that in many cases during the problem solving process they had just watched, Gina was correct in the direction she wanted to lead the group. The interviewer asks Gina why she often did not proceed in the direction proposed. In response, Gina refers to Segment 1b specifically.

After Lisa and Jessica corrected Gina's velocity-time graph with the conclusion that the line must have a positive slope, Gina in lines 23 – 25 says, "But it would be like…this, no we're assuming." When she says these words, she mimes drawing a velocity-time graph with a positive slope, but below the x-axis. Gina decides they are assuming the velocity is positive, and draws the line above the x-axis. Then she attempts to write an expression for the displacement using the area under the velocity-time graph. When she asks for help in lines 26 – 30, Lisa interrupts and comments, "She's confusing herself."

The original analysis of this segment concluded Gina had an opportunity for a social persuasion experience in lines 31 – 32, when Lisa interrupts her. When Gina comments on these two clips in the post-hoc interview she confirms this opportunity,

> And then the fact that she [Lisa] was like, 'She's totally confusing herself.' Maybe that made me feel, like I wasn't doing the right thing {looks down at the table, and shakes her head slightly}.

In Gina's reaction to the problem solving session we see her focus on Lisa's interruption comment in lines 31 – 32, and evaluates the entire thing as, "…made me feel, like I wasn't doing the right thing." We see evidence in Gina's statement that the interrupting comment from Lisa impacted her confidence in her ability to move forward. The message from Lisa is not a direct comment on Gina's ability, but rather an indirect message that Gina interpreted. The event Gina identifies aligns with what we interpreted as a *SPO*, thus demonstrating that even indirect messages as characterized by *SPO*s are sometimes taken up and impact self-efficacy.

4.5.3. Mastery Experience Opportunities

Identifying and Characterizing Mastery Experience Opportunities

Often *mastery experience opportunities (MEO*s) are the easiest types of *SEO*s to observe unfolding. We characterize *MEO*s by showing evidence that a task is completed and that someone offers an evaluation of that task. This evaluation could take different forms: either verbally suggesting the product is good/bad, using gestures such as nodding the head to indicate satisfaction/dissatisfaction, or moving forward to the next step in the process that relies on the previous task being completed correctly.

In Segment 1 several *MEO*s unfold as the students work through representing a velocity-time graph. When Gina turns to the board, she focuses on drawing the velocity curve on the graph. In line 1 – 22, a series of *MEO*s for Gina occur. Initially, Gina proposes that graph looks somewhat curved. Jessica shakes her head, indicating no, in lines 5 – 7 and corrects Gina, providing Gina with an opportunity for a mastery experience for drawing velocity-time graphs. Gina again attempts to draw the line, but proposes that there are actually two possibilities (one with a negative slope below the x-axis, or one with a positive slope above the x-axis). Again, Lisa and Gina evaluate this proposal by comparing the line with the information from the acceleration-time graph. In lines 20 – 22 Lisa points out that the line must have a positive slope, and thus only one of the lines is a possibility. Gina may reflect upon any one of these events and find that they have influenced her confidence in her ability to correctly represent the curve on a velocity-time graph. As such, any one of these events may be interpreted as a *mastery experience opportunity* for Gina.

Mastery Experiences are De-Emphasized through a Focus on Opportunities

When examining the post-hoc interviews, there is no evidence of the *mastery experience opportunities* identified in Segment 1 being taken up by the participants. The lack of *mastery experience opportunities* is initially surprising as the literature review demonstrated that mastery experiences are often viewed as the predominant source of self-efficacy. I propose that the lack of emphasis on mastery experiences in the analysis in the current paper is an artifact of the methodology used. Characterizing opportunities to influence self-efficacy in the moment and using video to recall the event allows the role of others to become clear, and thus places less emphasis on the performances of a single individual. As a result, the methodology de-emphasizes *MEO*s, while highlighting the role of *VLO*s and *SPO*s.

While the focus on real-time moments is of particular importance when considering mastery experiences, it is important that there is not evidence that all of the opportunities we have identified in this short segment are taken up regardless of the source-type. I contend that the lack of reference to an event does not mean that self-efficacy was not impacted in that moment, but that the moment does not stand out from others when reviewing the problem-solving session. I argue that demonstrating a portion of the identified *SEO*s being taken up provides validity for the method and that a lack of evidence does not prove the method to be ineffective, but yields information about the affordances of a focus on opportunities to impact self-efficacy.

4.5.4. A Focus on Opportunities Provides a New Perspective on the Sources of Self-Efficacy

The present paper has demonstrated that opportunities for self-efficacy to be influenced can be observed in actions as they are occurring. Using the theoretical understanding of what characterizes the various sources of self-efficacy this paper demonstrates the ability to observe three of the four sources of self-efficacy. Initially the intent was to observe information about *physiological state opportunities* (*PSO*s), but it was found to be difficult to infer information about the current excitement or anxiety of the participants through the video. The difficulty in finding *PSO*s may have been partially because the majority of the time the faces of the students were hidden from the camera, and thus it was not possible to infer information from facial expressions. Nevertheless, this work demonstrated the ability of characterizing the other three sources *MEO*s, *VLO*s, *SPO*s in the present-tense moment of the experience occurring.

The utility in understanding the sources of self-efficacy as opportunities in the present moment lies in the implications it holds for application. Understanding the development of self-efficacy only through the way participants recall events does not allow researchers or instructors to infer how to make those events occur. As Bandura [8] notes "recall involves a process of reconstruction rather than simply retrieval of events," (p.90). As such, only considering self-efficacy from these reconstructed recollections means that it may be difficult to ascertain the series of events that actually occurred and which then led to the particular reconstruction. To this end, looking at self-efficacy experiences from the past and opportunities for self-efficacy experiences in the present through video analysis allows researchers to make connections across time and hypothesize not only how the interpretation affects confidence in capability, but also how those events are constructed.

It also seems relevant that the *vicarious learning opportunities* and *social persuasion opportunities* characterized in this paper are particularly subtle events, yet had a direct influence on student self-efficacy. In studies in which participants are asked to recall the events that influenced their perception of capability, the subtle nature of these opportunities may be washed out by the abundant opportunities for mastery experiences, or the tendency for individuals to recall events that centered on their own actions. When analyzing this data for *MEO*s, *VLO*s, and *SPO*s, we see that many of these opportunities occur simultaneously. As such, when students articulate events from memory the salient features they mention may focus primarily on the *MEO*s. When students are provided with a video playback of the experience, a focus on *VLO*s and *SPO*s appears. As such, these results suggest that these subtle events do impact student self-efficacy, but they are not necessarily verbalized when students are asked to recall what influenced confidence in capability. The difference in prominence in memory may be the reason why mastery experiences dominate much of the research results into sources of self-efficacy [25,31,33]. The difference in saliency may be the reason why when participants are interviewed at length sources such as vicarious learning and social persuasion become more prevalent. Possibly, ample time for reflection on events or video evidence of the event itself, is needed to recall these more subtle opportunities for social persuasion and vicarious learning.

Another area that Bandura [8] hypothesized to be of particular influence is in how these sources of self-efficacy interact with one another to instill a sense of confidence in capability. In analyzing the present-tense for opportunities for self-efficacy, multiple opportunities for influence on self-efficacy can be characterized in a single event. Furthermore, as evidenced by the impact of Gina's drawing two velocity-time graphs on Lisa, Jessica, and Gina, the influence of a single event may have an impact on multiple participants in a single instant in time. As such, this method of understanding and describing *self-efficacy opportunities* may provide a mechanism for beginning to understand how the sources of self-efficacy interact with each other and can be interpreted as either a single event in the past, or as two separate pieces of information that become intertwined when evaluating confidence in ability for a similar task at a later point.

4.6 Conclusion And Implications

Analysis of a problem-solving episode from a group of three students has revealed that it is possible to characterize *opportunities* for self-efficacy to be influenced without asking the participants to reflect on memories of past events, and correlation of these *opportunities* with the post-hoc interviews suggests that these characterizations are valid. These results may be particularly relevant to researchers and teachers in attempting to influence self-efficacy. In purely relying on recollection of events, subtle influences such as those from vicarious learning opportunities and social persuasion opportunities may be washed out, and result in the appearance that performance accomplishments dominate evaluations of academic capability for students.

Further, this work has demonstrated that the use of video to examine events as they occur as well as to have students reflect on these events provides new information on the development of self-efficacy, particularly on the role of others. This work proposes that an exploration of *self-efficacy opportunities* would aid an investigation into the development of self-efficacy, particularly when combined with recollected self-efficacy experiences and measures of changing self-efficacy. With the understanding of how various learning environments construct *SEO*s, how various students interpret the opportunities, and these interpretations influence self-efficacy, it becomes possible to design events to impact self-efficacy in science in ways that will lead to increased success and persistence in science.

References (Chapter 4)

[1] P. J. Mulvey and S. Nicholson, *Enrollments and Degrees Report, 2006,* AIP Report No. R-151.43, 2008.

[2] H. B. Carlone and A. Johnson, J. Res. Sci. Teach. **44**, 1187 (2007).

[3] Z. Hazari, G. Sonnert, P. M. Sadler, and M. C. Shanahan, J. Res. Sci. Teach. **47**, 978 (2010).

[4] K. K. Perkins, W. K. Adams, S. J. Pollock, N. D. Finkelstein, and C. E. Wieman, in *Proceedings of the 2004 Physics Education Research Conference, Sacramento, CA, 2004*, edited by J. Marx, P. Heron and S. Franklin , New York, 2004), p. 61.

[5] L. E. Kost-Smith, S. J. Pollock, and N. D. Finkelstein, Phys. Rev. ST PER **6**, 020112 (2010).

[6] A. Miyake, L. E. Kost-Smith, N. D. Finkelstein, S. J. Pollock, G. L. Cohen, and T. A. Ito, Science **330**, 1234 (2010).

[7] L. E. Kost, S. J. Pollock, and N. D. Finkelstein, Phys. Rev. ST PER **5**, 010101 (2009).

[8] A. Bandura, *Self-efficacy: The Exercise of Control*, edited by S. F. Brennan and C. Hastings (W.H. Freeman and Company, New York, NY, 1997).

[9] S. Andrew, J. Adv. Nurs. **27**, 596 (1998).

[10] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. **31**, 356 (1984).

[11] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. **34**, 293 (1987).

[12] K. D. Multon, S. D. Brown, and R. W. Lent, J. Couns. Psychol. **38**, 30 (1991).

[13] J. Pietsch, R. Walker, and E. Chapman, J. Educ. Psychol. **95**, 589 (2003).

[14] J. Dalgety and R. K. Coll, International Journal of Science and Mathematics Education **4**, 97 (2006).

[15] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. **33**, 265 (1986).

[16] S. D. Brown, R. W. Lent, and K. C. Larkin, J. Vocat. Behav. **35**, 64 (1989).

[17] D. A. Luzzo, P. Hasper, K. A. Albert, M. A. Bibby, and E. A. Martinelli Jr, J. Couns. Psychol. **46**, 233 (1999).

[18] A. M. L. Cavallo, W. H. Potter, and M. Rozman, Sch. Sci. Math. **104**, 288 (2004).

[19] L. E. Kost, S. J. Pollock, and N. D. Finkelstein, in *Proceedings of the 2009 Physics Education Research Conference, Ann Arbor, MI*, edited by M. Sabela, C. Henderson and C. Singh (AIP, Melville, NY, 2009), p. 177.

[20] K. A. Shaw, in *Proceedings of the 2003 Physics Education Research Conference, Madison, 2003*, edited by J. Marx, S. Franklin and K. Cummings (AIP, New York, 2003), p. 137.

[21] V. Sawtelle, E. Brewe, and L. H. Kramer, in *Proceedings of the 2010 Physics Education Research Conference, Portland, 2010,* edited by C. Singh, M. Sabella, S. Rebelllo, (AIP, Melville, 2010), p. 289.

[22] A. Bandura, Psychol. Rev. **84**, 191 (1977).

[23] K. O. Moe and A. M. Zeiss, Cognitive Ther. Res. **6**, 191 (1982).

[24] A. Bandura, Annu. Rev. Psychol. **52**, 1 (2001).

[25] S. L. Britner, J. Res. Sci. Teach. **45**, 955 (2008).

[26] S. Lau and R. W. Roeser, Educational Assessment **8**, 139 (2002).

[27] V. Sawtelle, E. Brewe, and L. H. Kramer, Manuscript submitted for publication (2010).

[28] R. M. Schwartz and J. M. Gottman, J. Consult. Clin. Psychol. **44**, 910 (1976).

[29] R. W. Lent, F. G. Lopez, S. D. Brown, and P. A. Gore Jr, J. Vocat. Behav. **49**, 292 (1996).

[30] M. A. Hutchison, D. K. Follman, M. Sumpter, and G. M. Bodner, J. Eng. Educ. **95**, 39 (2006).

[31] R. W. Lent, S. D. Brown, M. R. Gover, and S. K. Nijjer, J. Career Assessment **4**, 33 (1996).

[32] R. W. Lent, F. G. Lopez, and K. J. Bieschke, J. Couns. Psychol. **38**, 424 (1991).

[33] T. Matsui, K. Matsui, and R. Ohnishi, J. Vocat. Behav. **37**, 225 (1990).

[34] K. A. Gainor and R. W. Lent, J. Couns. Psychol. **45**, 403 (1998).

[35] F. G. Lopez and R. W. Lent, The Career Development Quarterly **41**, 3 (1992).

[36] E. L. Usher and F. Pajares, Contemp. Educ. Psychol. **31**, 125 (2006).

[37] M. Hutchison-Green, D. Follman, and G. Bodner, Journal of Engineering Education **97**, 177 (2008).

[38] D. Palmer, Res. Sci. Educ. **36**, 337 (2006).

[39] A. L. Zeldin and F. Pajares, Am. Educ. Res. J. **37**, 215 (2000).

[40] A. L. Zeldin, S. L. Britner, and F. Pajares, J. Res. Sci. Teach. **45**, 1036 (2008).

[41] E. L. Usher and F. Pajares, Rev. Educ. Res. **78**, 751 (2008).

[42] F. Pajares, M. J. Johnson, and E. L. Usher, Res. Teach. Engl. **42**, 104 (2007).

[43] R. M. Klassen, J. Educ. Psychol. **96**, 731 (2004).

[44] G. Hackett and N. E. Betz, J. Res. Math Educ. **20**, 261 (1989).

[45] G. Hackett and N. E. Betz, J. Vocat. Behav. **18**, 326 (1981).

[46] F. Erickson, *Ethnographic microanalysis of interaction* (Academic Press, San Diego, CA, 1992), p. 201.

[47] D. Ratcliff, *Video methods in qualitative research.* (American Psychological Association, Washington, DC, 2003), p. 113.

[48] E. Brewe, V. Sawtelle, L. H. Kramer, G. E. O'Brien, I. Rodriguez, and P. Pamelá, Phys. Rev. ST PER **6**, 0106 (2010).

[49] D. Hestenes, M. Wells, and G. Swackhamer, Phys. Teach. **30**, 141 (1992).

[50] E. Brewe, L. Kramer, and G. O'Brien, Phys. Rev. ST PER **5**, 13102 (2009).

[51] D. Hestenes, Am. J. Phys. **55**, 440 (1987).

[52] E. Brewe, Am. J. Phys. **76**, 1155 (2008).

[53] M. Wells, D. Hestenes, and G. Swackhamer, Am. J. Phys. **63**, 606 (1995).

[54] D. M. Desbien, PhD Arizona State University, 2002.

[55] P. D'Alessandris, *Spiral Physics*.

[56] J. W. Creswell and D. L. Miller, Theor. Pract. **39**, 124 (2000).

CHAPTER 5 IDENTIFYING SEOS IN MODELING INSTRUCTION

5.1 Introduction

With the goal of improving the participation of traditionally underrepresented groups in physics, Florida International University (FIU) has implemented a multi-faceted reform of the introductory physics sequence. A central component of this reform effort has focused on the implementation of Modeling Instruction [1] as an integrated laboratory and lecture course replacing the traditional Introductory Physics with Calculus I & II sequence. In the years that have followed its implementation in 2004, the physics education research group at FIU has demonstrated Modeling Instruction's positive impact on students enrolled in the course. Modeling Instruction has been demonstrated to improve student conceptual understanding for all students [2], to improve attitudes regarding what it means to learn and do science [3], to improve retention of traditionally underrepresented groups [2], and to increase the physics self-efficacy of students in the classroom [4]. The success of the Modeling Instruction classroom has been well documented, thus the physics education research group has focused its attention on the mechanisms by which Modeling Instruction has achieved these successes. This paper focuses on understanding the mechanism behind one success: the improved self-efficacy of students in the classroom.

5.2 Self-Efficacy

The confidence in one's own ability to perform a specific task, or one's self-efficacy, was hypothesized by Albert Bandura in an effort to explain human behavior [5]. Initially much of the work on self-efficacy centered on addressing the behaviors of overcoming phobias [6], but researchers also turned toward self-efficacy theory to understand career choices [7--9]. The work on career choices and self-efficacy provided strong links between an individual's confidence in their ability to perform the necessary job duties and certain career choices [8]. As the work between self-efficacy and career choice proved fruitful researchers began exploring the role of self-efficacy in academic settings.

Particularly in the areas of math and science, research demonstrates that self-efficacy strongly predicts achievement in high school and university science [10--12] and mathematics classes [9,13,14]. In addition to success in the classroom, self-efficacy accounts for a large proportion of the variance in science and mathematics persistence [15]. These findings are supported with work from a multitude of studies demonstrating that mathematics self-efficacy is strongly associated with science-based career choices [9,16,17]. In physics, self-efficacy has also been linked to performance in introductory classrooms [18,19]. As we can see, considerable work has focused on the link between self-efficacy and success, but much less research has focused attention on understanding how self-efficacy develops [20,21]

5.2.1. The Influence of the Four Sources of Self-Efficacy

When Bandura [5] outlined his Social Cognitive Theory to explain behavioral change and introduced self-efficacy as a key component, he also discussed the types of experiences that build up self-efficacy. He theorized four categories for these experiences [22]: *personal mastery experiences*, *vicarious learning* experiences, *social persuasion* experiences, and the *physiological state.*

While Bandura argued that theoretically the greatest influence on the development of self-efficacy would come through an individual's experience with all four types of sources, he acknowledged that most people tend to rely on one type of experiences more than the others. Bandura theorized that *mastery experiences*, characterized by successful performances or repeated failures, would be the most influential source of the development of self-efficacy [22].

Vicarious learning experiences, the second source of self-efficacy, are derived from watching the performance of other individuals. When individuals observe others succeed or fail at tasks, they gather information on the likelihood of themselves succeeding or failing at a similar task. *Vicarious learning* experiences have the largest impact on self-efficacy when the observer perceives the performer of the task to be similar to themselves [21,23].

The third source of self-efficacy, *social persuasion*s*,* was posited by Bandura [22] to have the largest impact on the self-efficacy of those who already have a strong sense of their capability. However, others have theorized that *social persuasion* messages received either directly through verbal statements, or indirectly through observations of society may have a more direct impact on women [8], and on those for whom collectivism plays an important role in their cultural values [24].

Finally, the fourth source of self-efficacy, the *physiological state*, deals with the current somatic state of the individual [22]. This source is particularly difficult to disentangle from the others. Bandura [22] notes that most of day-to-day experiences carry information that influence our emotions and thereby our somatic states. Further, these states primarily act as a co-effect on current self-efficacy beliefs impact the way we interpret the current information and dictate what our physiological response will be [8,22]. Because of this source's mediating effect on the other sources of self-efficacy, we choose to focus our attention in this paper on the other three sources of self-efficacy: personal *mastery experiences*, *vicarious learning* experiences, and *social persuasion* messages.

While research on the impact of self-efficacy on career decisions, and on success is widespread, the work on the development of self-efficacy is less extensive and at times presents conflicting results [20]. We propose that this is not a difficulty of the theory of self-efficacy, but rather a question of method and focus. In the following section we propose an alternative method for investigating the development of self-efficacy that focuses our attention on providing a variety of experiences to all students.

5.2.2. Focusing on Creating Variety in Types of Experiences

Analyses focusing on the development of self-efficacy have primarily focused on identifying the most critical source for particular groups of students. Although some research has pointed to *mastery experiences* as the most influential source of self-efficacy [25--27], other research has suggested the most important source varies with gender [10,21,28,29], with ethnicity [24,30], and with the definition of peer used [23]. As a result, it appears impossible to say with certainty which source of self-efficacy should be the one that we focus our attention upon when designing interventions to impact self-efficacy.

On the contrary, the best approach appears to be one in which all four sources of self-efficacy are targeted at once [31], with the aim of providing a plethora of types of experiences so that we provide the right experience to the right person at the right time. Indeed, Bakken et al. designed an intervention targeting all four sources of self-efficacy and found that biomedical research self-efficacy did improve as a result of the intervention [32]. Interventions that focus on providing all four sources of self-efficacy are not able to say which one particular experience made the difference, instead they focus on providing a variety in the hope that the type of experience each participant would attend to would be presented through the course of the intervention. A benefit of this approach centers on the ability to target multiple individuals at one time. However, a difficulty lies in creating meaningful activities that provide opportunities for all four types of self-efficacy experiences.

5.2.3. Investigating the Development of Self-Efficacy to Design Interventions

The influence of each of the theoretically derived sources on an individual's self-efficacy is not entirely clear. Yet we have evidence that when an intervention is designed to address all four of the sources, the intervention is successful in improving self-efficacy overall [32]. As such, it seems pertinent to attempt to identify singular events that provide ways of attending to a variety of types of self-efficacy experiences. As a result, we sought an alternative way of investigating the development of self-efficacy.

Studies investigating the development of self-efficacy through the four sources rely on participants reflecting on past events and accurately recalling how the event impacted their self-beliefs about capability. The reliance on reconstructed memories directly aligns with the theoretical viewpoint of Bandura [5,22] who described the importance of self-efficacy building events lying not in the event itself but in how an individual interprets an event. Nevertheless, Bandura [22] also suggests that the way an individual remembers an event is not likely to be an accurate reproduction of how the event actually occurred. Conflicting results from previous studies combined with Bandura's [22] assertion that self-efficacy develops from the interpretation of events create difficulties for researchers and implementers who would like to design events to have a positive impact on student self-efficacy. With this in mind, I propose an alternative method for studying the development of self-efficacy with a focus on *self-efficacy opportunities (SEO*s) [33].

By attending to *SEO*s, we move from a focus on interpretation of past events to analyzing the way in which events unfold in real time. An analysis of opportunities provides us with a way of discussing how to construct events to target particular sources of self-efficacy. We cannot say with certainty that all of the identified opportunities are taken up and impact self-efficacy, but a previous work has demonstrated the validity of using *SEO*s to identify events that do impact the self-efficacy of individuals [33]. As such, I expect that within any set of identified *SEO*s, some will be taken up by participants and some will not, though the analysis of *SEO*s does not allow us to identify the particular opportunities that will impact self-efficacy. Instead, the analysis of events for *SEO*s focuses the attention on the ways particular events may be constructed to provide a variety of types of opportunities for self-efficacy to be impacted.

The assumption underlying this technique is based upon the intervention from Bakken et al. [32] that suggested providing a medley of *SEO*s creates a strong possibility of positively impacting self-efficacy. We maintain that because of the variance in the way individuals attend to particular characteristics of events we cannot characterize *events* as having a positive or negative impact on self-efficacy (for further discussion see [17,20,22]). Rather, we assert that even events that may be frustrating or challenging for some, can still act as positive self-efficacy experiences for others. As a result, we focus our attention on understanding events that provide a variety of types of *SEO*s instead of looking for positive impacts alone.

5.2.4. Investigating Opportunities to Influence Self-Efficacy

We apply the framework of *SEO*s to analyzing events from a Modeling Instruction environment. In previous work we have shown Modeling Instruction has positive effect on self-efficacy over the course of the first semester of introductory physics [4]. Traditional lecture instruction was found to have a negative impact on *mastery experiences*, *vicarious learning* experiences, and *social persuasion* experiences for all students. Modeling Instruction had no significant effect on the sources of self-efficacy for male students or on *mastery experiences* and *vicarious learning* experiences for women (which we contend is a positive result). Modeling Instruction also showed a significantly positive effect on the *social persuasion* source for female students.

Our goal in this analysis is to provide a beginning of a mechanism for how Modeling Instruction positively impacts self-efficacy. We approach this task through a demonstration of how single Modeling centered events provide a variety of types of *self-efficacy opportunities*. To address this issue we take a key component of Modeling Instruction, developing and deploying scientific models, and consider how *SEO*s unfold in two contexts (applying a well understood tool and extending the tool in a new situation) critical to a Modeling Instruction classroom.

5.3 Modeling Instruction

Modeling Instruction (MI) is a reformed pedagogical approach to physics that centers on the qualitative and quantitative development and testing of physical models. The reform effort can be described as the integration of three components. The first, the

Modeling Theory of Science [34] posits the activity that practicing scientists engage in is the development and deployment of scientific models. Underlying the pedagogical implications in MI is the idea that students should be engaged in activities that mimic those of practicing scientists. The Modeling Theory of Instruction [34--37], the second component, which provides a guide to the instructional practices that achieve the goal of having students engage in authentic scientific practices. The Modeling Theory of Instruction brings a coherent set of instructional objectives that center on model development and deployment into conjunction with a student-centered classroom environment. Finally, the third component of MI, Modeling Discourse Management, answers the question of what role the instructor is to play in this environment [38,39]. In the following sections we will go into further detail describing the first two components of Modeling Instruction, but will leave Modeling Discourse Management as a discussion for a future work.

5.3.1. Modeling Theory of Science & Modeling Theory of Instruction

The key assumption behind the Modeling Theory of Science (MTS) is that practicing scientists structure their declarative knowledge according to a set of coherent internal mental models, and when developing new knowledge apply these models to a particular context while at the same time refining those already in existence. Hestenes [36] argues that scientists generally agree with this assumption, but often have difficulty articulating a definition for these models. Nersessian, through a cognitive historical analysis has provided evidence that famous expert scientists throughout history such as Maxwell, Galileo, and Einstein have all used mental models when developing new ideas, suggesting that the idea that scientists develop and deploy models has been in place for centuries [40,41].

The Modeling Theory of Science guides the Modeling Theory of Instruction (MTI) through a fusion of coherent instructional objectives centered on model development and deployment and a student centered classroom environment that is designed to authentically replicate the activities of practicing scientists. A central tenet of MTI is the idea that students should work through developing and deploying models on their own. As Nersessian [40] describes, the process by which scientists construct and validate their knowledge is often a tacit process. Thus, it is difficult to articulate and make explicit all of the elements that are required to successfully move through a model development/deployment cycle. Requiring students to work through the cycle themselves while attempting to make the process they are going through explicit means the students receive both implicit and explicit messages about what it means to do science and how scientific knowledge is built and validated.

5.3.2. Organization of Scientific Models

Before we can move to a discussion of how models are developed, we first must discuss the organization of scientific models. There are two levels of models that are important in Modeling Instruction (MI). First are the *basic models*. These are the abstract and general models that build up a scientific theory (e.g., particle models and rigid body models build up Newtonian theory) and account for the various conceptions, rules, and tools that are necessary to build up a theory [34]. A basic model is a simple, but comprehensive, model that has been abstracted away from any specific context in such a way as to allow for merging into more complex models.

The second type of model commonly found in the MI classroom are what Halloun [34] refers to as *subsidiary* models. These models are simplified versions of the basic models, where particular assumptions and constraints have been placed on the basic model such that the scope of the subsidiary model is much narrower. These models often are used early in instruction when building up the basic models, and are often seen when students deploy basic models to describe/predict a particular phenomenon. For the purposes of this paper we will refer to the subsidiary models as *specific* models in reference to their applicability to only one particular physical context.

5.3.3. Developing Specific Models through Deploying Basic Models

Hestenes [36] first attempted to outline a modeling cycle for instruction, but his paper is cited as difficult to read and understand [1]. As a result, Brewe set out to provide a clearer description of the model development cycle as seen in an introductory physics classroom. In doing so he outlines five steps that are used in the MI classroom to develop the basic models that make up Newtonian theory: (1) *introduction and representation*, (2) *coordination of representations*, (3) *application*, (4) *abstraction and generalization*, and (5) *incremental refinement* [1]. In his paper Brewe lays out how students move through the process of developing the constant acceleration basic model by starting with describing movement in front of motion detectors with motion maps, progressing to coordinating the motion maps with kinematic graph representations, developing equations through a series of graphical descriptions, and finally generalizing a set of rules from several situations to develop a basic model. The basic model is then continually revisited in new situations and revised to incorporate new representations, to develop applications of old representations for new situations, and to extend the model to include causal elements such as forces and energy.

The process of building up a set of about 6 – 8 basic scientific models structures the content for the introductory physics MI class [1,36]. The majority of the class time is spent on the inherently linked processes of developing and deploying a set of specific and basic models. When faced with a new context, the first step to creating a specific model of the situation is to choose which basic model should be applied, which is directly tied to Brewe's first stage of the model development cycle of introduction and representation [1]. By making assumptions about the relevant physical phenomenon and placing particular features at the forefront, students introduce and create representations describing the specific model. Inevitably a coordination of these representations follows, thus entering stage two of the modeling process. However, a significant difference between developing a specific model and deploying a basic model enters at this point. The basic model carries a set of heuristics that govern how these representations should relate to one another (e.g. the slope of velocity-time graph should be constant in the constant acceleration model). As a result, when developing a specific model through deploying a basic model, the introduction and coordination of representations stage and the application stage mix together and repeat often.

Through developing specific models students better develop their understanding of the basic models, and of the activities of practicing scientists. The mantra in the MI environment is "THE MODEL IS THE MESSAGE (p. 446)" [36], and it is often less important to the instructors that the students choose the best set of constraints and assumptions when modeling a new situation than that they effectively employ the deployment and development tools at their disposal. As a result, specific models may vary somewhat from student group to student group (although ideally they are consistent) for a particular phenomenon. Although the same basic model may be deployed, depending on the features of the phenomenon the students identified as particularly relevant, different representations and assumptions may be used in developing the specific model.

In this paper, I focus on roles the model deployment/development cycle often plays in the MI classroom: practice in application of representations through modeling a familiar situation, and refinement of the basic model through modeling new situations by extending the representation. In this analysis I will focus on an episode where one situation serves both of these purposes for the students in the study.

5.4 Methods

The previous sections of the present paper have described the purpose of the work to investigate the model development/deployment cycle and to describe the *self-efficacy opportunities* (*SEO*s) that are present when students are applying a representation from a basic model or extending the use of that representation. The primary goal in this analysis is to characterize the *SEO*s that are present as students move through the process of developing a specific model for a physical phenomenon while deploying the basic model of constant acceleration. As a result, I focus this analysis using a microanalytic lens [42] describing in detail the interactions we observe taking place and characterizing both the stages of the modeling process and the *SEO*s present during the process.

5.4.1. Participants

Three female students who were currently enrolled in the same Modeling Instruction classroom participated in this study. At the time of the study all three were in their junior year of college, declared biology majors, who described themselves as being on a pre-medical school track. An experienced instructor, well versed in all elements of MI, led the introductory physics class. The participants, Lisa, Gina, and Jessica, were all part of a cohort in the university system that focuses on quantifying biology in the classroom. Lisa and Gina are identical twin sisters, and Jessica was both a friend and a colleague. Jessica had the most prior experience with physics. She had taken three physics classes in high school, but she described in later interviews that she learned more physics in one year of Modeling Instruction than she learned in all three high school physics classes. Neither Lisa nor Gina had taken any physics prior to the Modeling Instruction class. All three women volunteered for the study, they were chosen for convenience of scheduling, and were paid for their time.

5.4.2. Data Collection

My study took place over the first month of the participant's Introductory Physics with Calculus I course. Participants took part in a series of four problem-solving sessions in which they were asked to work together on a problem chosen to be just at the edge of what they had learned in class. The sessions were timed to take place in parallel to the classroom development of the constant acceleration basic model. The first session was scheduled while the students were still working to describe motion with a constant velocity and was intended to make the participants comfortable with the prospect of working on the problem together in front of a camera. The second session elicited the student's knowledge of the rules that govern the consistency between kinematic graphs in a uniform acceleration situation. The third session engaged the students in using algebraic representations to describe a 1-dimensional constantly accelerating particle. Finally, the fourth session, and the focus of this paper, centered on eliciting their comprehension of a composite system that includes both 1-dimensional and 2-dimensional motion with distinct accelerations. Our goal is to focus on the model development process the students go through, and as such we focus the discussion in this paper on the fourth session since the students had the most experience with the modeling process by this time.

While we collected these data outside of the classroom, we designed the sessions to closely mimic the activities that took place within the MI environment. The participants worked in a group of three, they completed the work on whiteboards (for a discussion of whiteboard use in the classroom see [37]), and they were asked to work on problems that were similar to those given in the classroom setting. Further, all of the students described the sessions as being like class in some way. Jessica compared the experience to a group exam (an exam in which students are placed in a group of three or four and given one grade for the combined work), while both Gina and Lisa referenced the type of problem and the expectation of working out a solution together on a whiteboard as being similar to the classroom environment.

5.4.3. Composite System Problem Solving Session

Lisa, Gina, and Jessica all participated in all four problem solving sessions. In each session the first author was present and clarified the activities that would take place. The participants were given a problem, chosen by their MI instructor to be similar to those used in class, but new to the students, and asked to spend 45 minutes working to get as far as they could on the problem. The problems were chosen to be just at the edge of the physics content knowledge the students had developed until that time. The choice of problems served two purposes: I expected if the problem was difficult the students would more readily speak aloud their thoughts and share the work with one another, and secondly because I wanted to see not only deployment of an already ramified model from the students repertoire, but the process the students would go through when faced with an unknown situation.

The session took place in a room adjacent to the participants' classroom that contained a large table and a set of whiteboards. The participants were asked to talk aloud as they worked on the problem in a design similar to that of Sherin [43], and the only interaction between the participants and the researcher present was to ask the students to speak up at times or to give a bit of guidance when the students stopped working productively. The present paper focuses on the microanalysis of two short clips from the fourth problem-solving session. The problem the students were given described a phenomenon that contains both a 1-dimensional constant acceleration portion and a 2-dimensional constant acceleration portion.

> *A mountaineer must leap across a 3.0m wide crevasse. In order to make the jump, she backs up 10m from the edge of the cliff, accelerates towards the cliff, and leaps at 35º above the horizontal. The mountaineer successfully makes the jump.* [44]

The first observation of this problem is that there is no question. Students were familiar with situations similar to this from the classroom where the goal usually centers on providing a complete model of the situation, and thus no single implication of that model is identified for the students to focus on (for more discussion on this type of problem-solving see [1]).

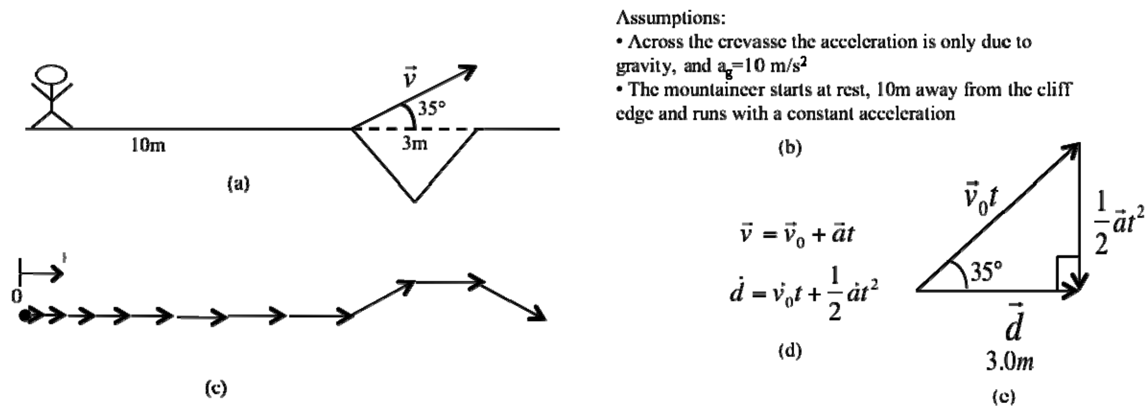

Figure 3. An Example of an acceptable specific model for the mountaineer's motion.
(a) A pictorial representation of the problem description. (b) A set of assumptions characterizing the model. (c) A motion map showing the constant acceleration of the mountaineer. (d) The vector equations used to find displacement and velocity in a uniformly accelerated particle model. (e) A whole vector diagram used to describe the motion across the crevasse.

The expected outcome of developing a descriptive model for this situation is an application of the uniformly accelerated particle basic model. An example of what one possible specific model could look like is depicted in Figure 3. The expected solution would contain several whole vector addition diagrams (e) [45], motion maps (c), and values for the minimum velocity the mountaineer requires to make the jump, the acceleration required to start from rest and achieve that velocity by the edge of the cliff, the height she jumps, and the time it takes her to complete the jump. Additionally, it is expected that the students will explicitly discuss the assumptions they make when modeling this situation (b), to check for consistency across the specific model they develop, and possibly to use kinematic graphs and pictorial representations (a) wherever they find them useful. Recall that the interest in the solutions to problems such as this are less concerned with the correctness of the calculations, and more with the consistency within the model developed.

At the time when the students were asked to model this situation, they had just completed developing a descriptive version of a constant acceleration basic model in class. In the previous class meeting the students had practiced applying whole vector triangles in two-dimensional, constant acceleration situations. Up until this point they had incorporated kinematic graphs, one-dimensional and two-dimensional motion maps, vector equations for displacement and velocity, and whole vector addition triangles into their descriptive model. The phenomenon of the mountaineer jumping the crevasse can be modeled as two distinct constant acceleration specific models: one for the motion along the 10m distance prior to the cliff edge, and another for the two-dimensional motion of the mountaineer leaping the crevasse. At this point in the class, the students would have had multiple opportunities to model both of these types of situations independently, but they had not yet seen a system combining both one-dimensional and two-dimensional motion. As such, we expected the students at times in this problem-solving session would be exercising well developed tools and at other times extending their knowledge into situations that are not as familiar.

5.4.4. Analytic Framework

Presented here is an analysis of the video using a microanalytic framework [42] which focuses the attention on the how of the interaction. Our goal lies in describing the process the participants go through when developing specific models through a lens of *self-efficacy opportunities* lens. In choosing clips to analyze we focused first on instances where the students are clearly engaged in the model deployment/development process.

Within these episodes we looked for places where the students were confidently utilizing already developed skills as well as cases where they were more tentative in their approach, indicating an extension of the model. The first clip we present depicts the students confidently using the two-dimensional whole vector addition triangle (see Figure 3.e) to develop a specific model of the mountaineer jumping the crevasse. In the second clip we again see the students using the same tool, but in this case they are applying it to a new situation, the composite system.

After the clips are chosen, the event is carefully transcribed, taking care to focus attention on the interactions that are non-verbal, such as gestures between individuals, head nods and gaze direction [46]. Next, the video is analyzed by characterizing *SEO*s [33] present in the event. I focus my attention on opportunities to build beliefs in capabilities centered on model building. In doing so I characterize *mastery experience opportunities* (*MEO*s) as times when an individual student performs a task and receives an evaluation of that task either by the others working with her, or by successfully moving forward on the problem. Similarly, when there is evidence that another individual observes the performance of a task and evaluation, it is characterized as a *vicarious learning opportunity* (*VLO*) for the observer. Finally, when messages about the students' abilities are communicated either verbally or indirectly through gestures, gaze direction, or nods, we characterize the event as a *social persuasion opportunity* (*SPO*) for the person receiving the message.

5.4.5. Reliability and Validity

In order to maintain reliability and validity in this work, several measures were used. First, the problem-solving sessions and subsequent analysis were designed through the collaboration of several researchers. In addition, throughout the design process, the data collection, and analysis a researcher reflection notebook [47] was maintained as a way of monitoring subjectivity and researcher reflexivity. For the analysis of both the modeling process and the *self-efficacy opportunities* peer debriefing [47] was used as a way of ensuring interpretations of the data were reasonable. Finally, though only 6 segments of transcripts comprised of approximately 4 minutes of data are presented in the present paper, an additional 20 minutes of data was analyzed to ensure the representative nature of the data and interpretations presented here [42].

5.5 Results and Discussion

5.5.1. Confidently Applying a Tool from the Constant Acceleration Basic Model

Immediately after reading the problem provided, the students analyze the two-dimensional portion of the situation. They draw a pictorial representation of the mountaineer jumping the cliff similar to that in Figure 3.a, and immediately move to creating whole vector diagrams that describe the displacement of the mountaineer from one edge of the cliff to the other. The correct whole vector diagram the students are discussing is shown in Figure 3.e, note that the students initially make a mistake and read the crevasse to be 30m wide instead of the correct 3.0 meters.

As Students Create a Whole Vector Triangle MEOs and VLOs Unfold

Segment 1: 1½ Minutes

Lisa: So our two equations were, {writing them on the board $\vec{d} = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2$}, it's freaky how I memorized it..

Jessica & **Gina**: Laughter.

Lisa: {Continuing to write on the board, $\vec{v} = \vec{v}_0$}. It's just v_0?

Jessica: plus a t.

Lisa: {finishes writing $\vec{v} = \vec{v}_0 + \vec{a}t$ on the board}

Lisa: So, if we use the triangle method here.

Lisa: {Steps to the side of the board, starts drawing a horizontal line and an upward sloping line}. So we know this {the horizontal vector} is 30. We know this {the angle in the triangle} is 35 degrees.

Gina: {Points to the upward sloping line Lisa has drawn}, v_0.

Lisa: {Writes v_0t where Gina pointed}

Lisa: And then...{draws a line to make a triangle connecting the other two sides}

Jessica: equal to ½*at*.

Lisa: Squared. {writing $½at^2$ next to the line she just drew}

Jessica: Mmhmm.

Gina: {Points to the left-most vertex of the triangle} *t* initial, and then points to the right most vertex.

Lisa: {Writes t_0 and t_f next to the vertexes}

Lisa: Why would you do that?

Gina: It's just {inaudible}.

Gina: Ummm....{points at the 30m on the bottom of the triangle}. Displacement. Equals *d* {mimes =*d* next to the 30m}.

Lisa: OK, so we have the displacement. We need to figure out *v* sub...OK, so...

Lisa: Here we have, an angle and a side.

In this clip we observe the students working together to construct and use a whole vector triangle for displacement. In lines 1 – 8 Lisa and Jessica work together to write the vector equations they developed in class for displacement and velocity. In the following chunk we see Lisa, Gina, and Jessica all working together to construct the displacement triangle shown in Figure 3 (lines 10 – 36). Looking at this clip for evidence of modeling, we see that the students confidently move through a model deployment process. The first thing the students do is to look for the primary features of the situation that determine which basic model applies. When Lisa proposes using the "triangle method" (line 10), she is referring to the whole vector addition tool they had recently developed in class as a part of the uniformly accelerated particle model for dealing with motion in two dimensions. By choosing this method, Lisa indicates that she sees the two-dimensional motion as a primary feature to be considered. Lisa does not hesitate in the transition from writing the vector equations (lines 1 – 9) to drawing the two-dimensional triangle (line 10), indicating that she is confident in her choice of which tool to apply. Further, we expect this sequence of events to impact her future confidence in her capability to perform a similar task. A *MEO* presents itself as Lisa proposes a set of equations to guide their model building (lines 1 – 9) and a focus on two-dimensional motion by drawing a whole vector triangle. Jessica and Gina evaluate this proposal of primary features by contributing to the process (lines 16 – 17, and 21).

As the students work through the process of introducing and representing the two-dimensional motion through building the whole vector triangle that represents displacement (lines 11 - 33), a *VLO* develops for Jessica. Lisa and Gina work together to draw the whole vector triangle (lines 11 – 20) that represents the two-dimensional motion. Together they draw the horizontal line that represents displacement and the 35^o angle (11 – 15), and label the v_0 side (lines 16 – 18), setting an example for Jessica of how to introduce and represent two-dimensional motion. We have evidence that Jessica is cognizant of the performance because in line 21 she contributes to the construction by giving the label for the third side. Later, when introducing and representing two-dimensional motion, Jessica may reflect on this event where she observed Lisa and Gina performing the task, and evaluate her belief in her ability to complete a similar task using this experience.

When the Students Limit the Model MEOs and SPOs are Created

<u>Segment 2: 42 Seconds</u>

37 **Lisa:** Are we going to assume acceleration is
38 due to gravity?

39 **Jessica**: {Nods her head} Mmhmm.

40 **Gina**: We have to.

41 **Lisa**: So, *a* equals {writing *a*= on the board},
42 are we going to use 10? To round it?

43 **Jessica**: Well we used that one in class.
44 {Shrugs} It makes it easier.

45 **Jessica**: {Turns to interviewer} We use 10
46 m/s instead of 9.81 to not complicate it so
47 much.

48 **Lisa**: We can do mental math.

49 **Lisa**: OK, so...

50 **Gina**: We can use this angle {points to the 35
51 degrees in the triangle} so it's...

52 **Lisa**: The law of sines?

Gina: Opposite over adjacent.

Lisa: {Writes "Law of Sines" on the board}
Do you wanna just do the Law of Sines?

Jessica: I didn't know how to do that,
cause...remember, yeah.

Lisa: OK, I'll explain it to you.

Gina: {Turns toward Jessica and laughs}

After the students have drawn the whole vector representation (see Figure 3), they return to picking out additional primary features from the situation. In lines 37 – 38 Lisa asks if they will assume the acceleration is due to gravity. The others agree, and Lisa goes on to clearly articulate their assumption on the board (line 41) and Jessica explains that they will assume the value of this acceleration to be 10 m/s^2 in order to be able to do the math in their heads (44 – 48). Assumptions play a critical role in deploying basic models, as they limit the scope of the model and describe the structure of the developing specific model.

We observe a *MEO* for Lisa unfolding in this clip as Lisa suggests using the assumption that acceleration is due to gravity (lines 37 – 38), and both Gina and Jessica confirm the suggestion (39 – 40). Lisa also suggests rounding the value to 10, and Jessica supports this idea (43 – 44). This series constitutes a *MEO* for Lisa. She may recall the event as evidence of her ability to make appropriate assumptions limiting the applicability of the specific model, and use the evidence to evaluate her confidence in her ability to perform a similar task.

At this point we see an example of how the heuristics that guide basic model deployment become an important consideration. Here, the students bring in a tool from the model that is paired with the whole vector triangles: the Law of Sines. When Jessica expresses uncertainty about using this method (lines 56 – 57), Lisa replies quite confidently that she can explain it to Jessica (line 58). A *SPO* for Jessica occurs at the end of this exchange. Lisa turns and offers to explain how to use the math (58), while Gina looks at Jessica and laughs (line 59). Regardless of what caused Gina to laugh at this point, Jessica may interpret it as a response to her uncertainty with the Law of Sines. As such, the laughter could communicate to Jessica that Gina finds it funny that she does not understand. Later Jessica might reflect on this event when considering her confidence in her ability to use the Law of Sines, or to solve a whole vector diagram, and the indirectly communicated message would impact her self-efficacy to complete the task.

A Unit Analysis Affords MEOs and VLOs

Segment 3: 38 Seconds

{3 minutes pass while the students apply the Law of Sines to the triangle they have created and calculate the length of one side}

Lisa: {Writes v_0t = 36.62} 36...need the other marker.

Lisa: 36.62, what's this in? Meters? Meters per second? No, cause there's time in there too.

Jessica: It's meters because there's m/s {points to v_0} and seconds {points to t}

Lisa: Meters, yeah.

Lisa: So, this whole side {points to the v_0t side of the vector triangle} is 36.62 meters. Does that makes sense? Yeah, because then this is in meters {writes m next to the 30 on displacement side of the triangle}. Because we can only add… {points to each side of the triangle, pauses at the ½at^2 side}...OK

Gina and Lisa spend the next few minutes explaining to Jessica how the Law of Sines works and afterwards, they apply the method to their own triangle to determine the v_0t side should be 36.62. In the intermediary 3 minutes, they realize the angle between the acceleration vector and the displacement vector should be 90^o and note that in the triangle. They get stuck for a little while on calculating the numbers, but they successfully find the value of the v_0t side of the triangle to be 36.62, and the subsequent transcript (lines 60 – 75) depicts the students deciding on the units that should be paired with this number.

We categorize this snippet on units as a mixture of the application and coordination of representations steps of the model deployment/development process. When we first enter the scene we see the students have completed the application of the Law of Sines to find the value for v_0t (lines 60 – 61). They finish this application step by finding the units for this value (62 – 66). Then we see Lisa attempt to coordinate the representations. She records the value for the v_0t side of the triangle (line 69) as a single value. It does not bother Lisa that they have neither the value of v_0 nor the value of t, because the representation treats the v_0t as a single value, and thus Lisa focuses on the quantity as a whole. The following unit analysis further validates this claim that Lisa views v_0t as a single quantity. She focuses her actions on finding that each side of the triangle is measured in meters, and she ignores that they do not know each variable independently. Rather, her attention remains on the model, and checking to be sure that the model is internally consistent.

We also see a series of *SEO*s unfolding within this series of events. Lisa sees merit in performing a unit analysis for the value of 36.62 (lines 60 – 67). However, when she initially attempts to check the units, she gets stuck (62 – 64). At this point Jessica steps in and models how to determine the unit through focusing on the combination of the *m/s* and the *s* (lines 65 – 66). The modeling of the performance creates a *VLO* for Lisa as she is clearly paying attention by her confirmation of Jessica's answer (line 67). Thus, her confidence in her ability to proceed when faced with another unit analysis may be impacted by this experience with Jessica. The same set of events constitutes a *MEO* for

Jessica. Lisa follows up Jessica's conclusion that the unit should be meters (65 – 66) by evaluating if this result makes sense in the rest of the diagram (lines 69 – 75). Jessica might reflect on this series of events and recall her success in evaluating units, and judge her self-efficacy to complete another unit analysis, and coordination of representations, based on this success.

Reviewing the *self-efficacy opportunities* we have identified in this series of clips (segments 1 – 3), we can see that there is a strong tie between the process the students are working through and the *SEO*s they experience. However, we note that the students are relatively successful in building a model for this 2-dimensional motion situation, as evidenced by their relatively linear progression, as well as the fact that they are all engaged in the same task, and only struggle with some basic calculator issues. Thus, we also chose to analyze a series of events where the students are not as certain about the path they should follow, and look for variances in the types of *SEO*s that are present there.

5.5.2. Hesitantly Extending the Application of a Tool from the Constant Acceleration Basic Model

In the second set of clips we analyze, the students are still working on the same problem of the mountaineer leaping the crevasse. By this point in the episode the students have successfully created a model describing the two-dimensional motion of the mountaineer as she makes the leap across the crevasse. They then returned to the one-dimensional motion that leads up to her making the jump. In doing so, they have recognized that the final velocity of this motion corresponds to the initial velocity from the two-dimensional portion, and that the value of the acceleration for this portion of the problem is unknown. At this point, however, they are at a standstill. They are unsure how to proceed as they feel they do not know enough information to take the next step. These segments represents a time when the students are uncertain about the steps that they take, but their focus is still on developing a specific model of the situation. Immediately prior to the following transcript all three students have been standing silently looking at the board. In segment 4 the students propose using the whole vector triangle addition method for solving two-dimensional motion to solve this one-dimensional problem. The diagram they are referring to in the follow transcript is shown in Figure 3.a and the whole vector diagram they end up drawing is shown in Figure 4.

Determining Whether the Whole Vector Triangle Applies Creates SPOs

Segment 4: 37 Seconds

Lisa: Cause we can't do the triangle {spans fingers along the velocity vector in Figure 3.a} taking into account… {running finger along the 10m the mountaineer runs}

…because that's not when she jumps off {moves finger along the velocity vector}. The 35 degrees are here {at the cliff edge} not there {at the beginning}, so...

Jessica: Wait! Didn't he {the professor} say that we can use, if we have any triangle {draws a dashed line from the mountaineer's starting position at an angle as shown in the $\frac{1}{2}at^2$ vector in Figure 4}.

Can't we make this {indicating the line she has just drawn and the velocity vector} into a triangle somehow? Well, make it fit {her lines don't match up}.

And then we do know this angle {between the velocity vector and the ground prior to the cliff edge}. When you think about it, because it's a straight line.

Jessica: {pauses, turns toward Gina and Lisa, shrugs her shoulders}

Lisa: {cocks her head to the side, as she looks at what Jessica has drawn}

Gina: {drawn-out whisper} tr-u-e.

Jessica: And we do know this side {the velocity vector} because this side is the same as that {points to the 2d whole vector displacement triangle they previously solved}. Isn't it? {Looks at Gina and Lisa}

Lisa: {hesitantly} Yeah.

Jessica: Can we? {shrugs, still looking toward Gina and Lisa}

Lisa: I don't know if we can do that. I guess.

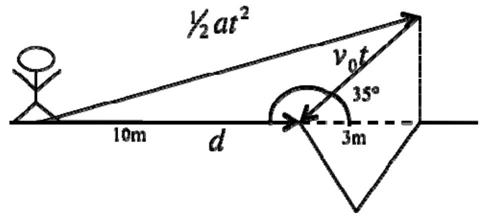

Figure 4. Whole Vector Diagram
The whole vector diagram the students construct for the one-dimensional motion.

The students had been stuck for some time prior to the beginning of this clip. Having just finished the analysis of the two-dimensional motion of the mountaineer jumping the cliff, they misappropriate the two-dimension tool and apply it to the situation of the mountaineer running in a straight line toward the cliff. Although the students express uncertainty in whether this is an appropriate move to take in solving the problem (lines 22 – 23, 32, 33-34, and 35) they proceed with a model development process that demonstrates an understanding of the importance of consistency within the model and the focus being on the model.

In the beginning of this clip we see Lisa trying to see if she can use the whole vectors triangles that they just successfully applied to the two-dimensional motion portion (lines 1 – 8). Clearly, this representation from the constant acceleration basic model is still fresh in her mind, and she would like to use it to represent the one-dimensional motion as well. Jessica takes up this idea, and suggests that it is possible to apply the tool as in this situation as long as the necessary conditions are present (lines 9 – 13). Jessica then molds the situation to fit these conditions (14 – 21) and asks the others to agree with her (22 – 23). The whole group appears uncertain as to whether applying this tools to this situation makes sense (22 – 35), but they decide to try it (line 35). As

Jessica finishes her initial arguments for the applicability of the method, a *SPO* unfolds for Lisa and Gina. Jessica finishes with a shrug and an uncertain question about whether the reasoning is sound as she looks toward Lisa and Gina for aid (lines 33 – 34). Looking toward Lisa and Gina creates a *SPO* for both of them as Jessica indirectly communicates that she believes they can evaluate her argument. Later, Lisa and Gina might reflect on events similar to this and judge the strength of their ability to appraise another's argument about the assumptions guiding a model development based on these experiences.

Making the Equation and Triangle Consistent Affords MEOs and VLOs

<u>Segment 5: 17 Seconds</u>

Lisa: {Takes a step forward} So this would be v_0t {pointing at the velocity vector}. And we are using this equation? {points at the displacement vector equation in Figure 3.d}

Jessica: Cause he said {points with marker toward the board} we don't know, like, it's not always going to be like that {points at the 2d whole vector triangle from previously}. They can just, move around.

Lisa: {Mover her hand to the dashed line Jessica drew} Yeah, this one could be acceleration and this one {the 10m line} could still be this one {points at the $\vec{d}$ in the displacement vector equation}.

Lisa: So they would just be swapped {holds two fingers up next to the two lines and rotates them}.

Gina: {Picks up a marker. Starts drawing another dashed line straight down from the one Jessica drew to the opposite of the cliff where the mountaineer lands}

Jessica: Mhm, cause she's accelerating in this direction {moves her finger along the dashed line she drew}

At this point Lisa starts working to develop the model by coordinating the representations they have thus far. Lisa indicates that if one of the vectors is v_0t (lines 37 – 38), they are using the vector equation that constructs these triangles (38 – 40), and the line Jessica drew is acceleration (lines 48 – 49), then the 10m distance could still represent displacement (49 – 51). As she talks through this reasoning, Lisa fluidly moves between the proposed triangle drawing and the vector equation for displacement, even referring to the horizontal line on the diagram by pointing to the $\vec{d}$ in the vector equation.

A *MEO* unfolds in this series as clearly from Lisa's perspective the vector equation and the whole vector triangle need to be in agreement before they can move forward with applying this tool of the model, and she works to make them consistent. Jessica provides evaluation of this task as she reasons that the acceleration vector makes sense, "cause she's accelerating in this direction" (lines 59 – 60). Here, Lisa and Jessica look for consistency across the problem description and the vector direction, and an opportunity for a *mastery experience* is created for Lisa. Similarly, we can look at this event from the perspective of Jessica and see a *VLO* for Jessica. She watches as Lisa makes the two representations consistent, as evidenced by her confirmation of the labels on the triangle (59 – 61). We might expect Jessica to reflect on this experience of observing Lisa at another time and assess her confidence in her own ability to perform a similar task. For Lisa and Jessica, the agreement between representations seems to be an important step in the solution, and the process itself affords opportunities to impact self-efficacy beliefs in coordinating these representations.

Evaluating the Application of the Triangle Provides Multiple MEOs

Segment 6: 33 seconds

{1½ minutes pass as Jessica and Lisa continue to work through whether the vector triangle can be used in this situation. Gina has been off to the side working on her own when she looks at what Jessica and Lisa have drawn}

Gina: Why is this ½at^2 {points to the vector Lisa and Jessica defined as acceleration}?

Lisa: Yeah, but then we have that angle {between the velocity vector and the 10m prior to the cliff}…

Gina: You have to use the entire triangle Lisa! {outlines large triangle made up by the acceleration vector, total 13m distance, and vertical dashed line she drew}

You don't use your own, cool triangle here {looks directly at Lisa}.

Lisa: OK {upward intonation, places the cap on the marker, steps away from the board}.

Gina: We use the entire one {again outlines the full triangle including the vertical line}.

Jessica: The only thing is that...there's two things going on {moves her finger between the 10m section and the 3m section of the problem}. So if we use the whole triangle...then I don't know...

Lisa: Exactly, we can't...

Jessica:...meshing it in. So the triangle we need to use is kind of {starts drawing}

Gina: And here {pointing at the 10m section} it's 1d motion.

Jessica: {Draws a new triangle on the board}

Lisa: Can we even use triangles during 1d motion? {shaking her head slightly} I don't even think that's possible.

The students continue developing this vector triangle for several minutes, with Lisa adding directional arrows to the vectors to make sure they add together correctly. Several times they express uncertainty with what they are doing including one point where Lisa exclaims, “I think we’re totally violating the laws of physics!” and Jessica responds with laughter saying, “We might be! Probably.” Nonetheless, they continue forward with the model until Gina, who has been working quietly to the side, enters the discussion and suggests that Lisa has been focusing on the wrong triangle (lines 62 – 72).

In segment 6 the students evaluate whether they have correctly deployed the rules of the basic model they have been using, and *MEO* for Gina unfolds. When Gina suggests that they have been focusing on the wrong triangle in the diagram (lines 68 – 69, 73 – 78), she calls into question the rules they have been applying up until that point. Jessica provides the evaluation of Gina’s suggestion when she starts to articulate a rule that regions with two accelerations need to be modeled separately by pointing out there are two things going on throughout the total 13 meters (lines 85 – 89). Gina responds to this recollection of the rule and further articulates the problem by saying that the 10m section is one-dimensional motion (93 – 94). Gina may recall this event at another time and judge her confidence in her ability to apply the rules of whole-vector addition triangles accordingly.

Additionally, we see from the end of this clip (96 – 98) that the entire sequence of events represents an unfolding *MEO* for all three of the participants. Throughout segments 4, 5, and 6, we have described the students working through a process of applying a tool of the constant acceleration model to the specific situation of the mountaineer running in a one-dimensional direction. They spend several minutes working together on this application, and while they express uncertainty about its applicability throughout the process, it is not until the end that they decide the one-dimensional motion does not allow them to use whole vector addition triangles (lines 96 – 98). The students evaluate this task, applying whole vector triangles to a situation, for themselves. As such, we can characterize the entire sequence as one large *MEO* centered on applying a tool from a basic model. The participants might later reflect on this event in evaluating the confidence in their abilities to apply a tool from a basic model in the future.

5.5.3. Both Extending and Applying the Tool Provides a Variety of Types of SEOs

Throughout the analysis of the clips described, we see that the students have a variety of *self-efficacy opportunities* presented to them. Part of the reason for this, we believe, lies in the task that the students are engaged in. All of the segments portray students who are focused on constructing specific models. We see evidence in segments 1 – 3 that the students see the representations as a coherent idea that must be internally consistent, and they use this idea to guide their model construction. Similarly, though the students are unsure of the applicability of the whole vector triangles in segments 4 – 6, they go about extending the rules that guide the representation while anchoring their reasoning in the idea that the model itself must be consistent. The students rely on each others' knowledge when constructing these models, which affords opportunities for both *vicarious learning* and *social persuasion* experiences.

In addition, we note that the argument for a focus on variety of types of *SEO*s rather than focusing on trying to make all events positive experiences is made apparent in the discussion of these clips. In several places *SEOs* that we have described are difficult to characterize as having either positive or negative influences on self-efficacy, as it depends on the particular attributes of the event that an individual focuses upon. Indeed, in an event such as those in segments 1 - 3 where the students are confidently applying a well developed tool, we might expect there to be only positive *SEO*s, but if we take a closer look at the opportunities in lines 60 – 75 of the transcript, we see that we cannot characterize the event as being distinctly positive or negative. As described earlier, we see a *VLO* for Lisa occurring in lines 60 – 67 as she attempts to complete a unit analysis for the 36.62 value and Jessica appropriately models the solution for her. The task lies in Jessica's calculation (65 – 66), and the evidence that Lisa is cognizant of the performance in her acceptance of the answer (line 67). On one hand, because Jessica and Lisa are friends and colleagues who often work together, Lisa might reflect on this sequence and see it as a positive experience showing her that someone who is very similar to her (Jessica) was easily able to calculate the units, and thus she should be able to do this as well. However, if Lisa feels that she has been struggling with these types of tasks when Jessica easily performs the unit analysis Lisa might compare her own performance to Jessica's and find herself coming up short. As a result Lisa might think that she will never do as well as Jessica, and this might negatively impact her self-efficacy.

In segments 4 - 6, when the students hesitantly attempt to apply the whole vector addition to one-dimensional motion, we might expect that the *SEO*s making up this clip would be primarily negative. However, even when we take the entire sequence of events, that we earlier classified as a *MEO* for all the students, and we ask whether it had a positive or negative impact on their self-efficacy, we find that it depends on how the students interpret the event. For instance, Jessica, who initially proposed that the whole vector addition might work in this case (lines 9 – 21) could view this experience as either negative or positive. The students spend several minutes on trying to apply the whole vector addition to this motion, and when they finally abandon the method just after segment 6, we might find Jessica reflecting and thinking to herself that she was completely wrong to suggest the tool and as a result less confident in her ability to apply this tool in another situation. However, we might also find that Jessica points out that even though she was the one who suggested it, she was not at all sure it was correct (see lines 22 – 23, 27 – 31, 33 – 34). As a result, Jessica might say that her uncertainty was well-founded, and while this method was not the correct approach, she knew that from the beginning. As a result, this *MEO* could actually have a positive effect on Jessica's self-efficacy in that she can trust her feeling when she is not sure something is the right way to go, because she was correct in this instance.

What we see from reviewing the various *SEO*s in these two clips, is that nearly all of them can be interpreted in these two ways. No one event has only the potential for a positive impact nor a purely negative impact on the students' self-efficacy. However, we have demonstrated that whatever type of source of self-efficacy any one of the students might attend to on a more regular basis, is present in these events. By creating a variety of types of *SEO*s the events have the potential to impact the students' self-efficacy in a variety of ways, thus creating opportunities to have a positive influence on all the sources of self-efficacy for all the students.

5.6 Implications and Conclusions

We have demonstrated in this analysis that a variety of types of *self-efficacy opportunities* are present during activities that mimic those that occur in the Modeling Instruction classroom. We contend that identifying this variety of *SEO*s is the first step to understanding how MI has had a positive impact on the self-efficacy for students enrolled in the course. Further, by looking at other events that occur in MI through the *SEO*s lens, we would expect to continue to see a variety of *SEO*s occurring in the majority of the activities taking place in this classroom environment. The limitations to our analysis lie primarily in our inability to distinguish the modeling deployment/development process from the emphasis on group work and consensus building discourse that is valued in the MI classroom. However, as we designed these sessions to be closely connected to the ways students work in small groups in the MI environment, we would nonetheless expect these finding to extrapolate to the larger classroom. Further it may be true that no one of these features creates the variety of *SEO*s, or the positive impacts on self-efficacy, but rather it is the integration of all of these factors that creates an environment where self-efficacy flourishes.

In contrast, we can imagine a classroom environment that does not provide a variety of opportunities to influence self-efficacy. A student, passively observing a lecturer working at a board in the front of the room is not afforded many types of opportunities for self-efficacy development. As their interaction is passively taking notes, we would not expect to see *mastery experience opportunities* unfolding because there is no indication of task completion or evaluation for the student. In terms of *vicarious learning opportunities* one might argue that the lecturer provides a model of how physics problems should be solved, but as the lecturer is not likely to be seen as a peer by the students in the class, these *VLO*s are unlikely to be present. In terms of their peers, the students in the class likely have little expectation to interact with one another, thus providing little to no opportunity to view how others perform, and therefore limiting *VLO*s. Finally, *social persuasion opportunities* are likely to be present in indirect messages that are sent when the instructor asks questions of the students, and by the make up of the class, but it is unlikely that messages about individual capability in completing specific tasks would be present in this format.

The primary differences between the passive student observer classroom and the Modeling Instruction environment that we have described in this paper resides in the difference in interaction and discourse that takes place in the classroom. In the passive observer setting the students have little to no interaction with one another, or with the instructor. Further, the discourse only occurs between the instructor and the individual student. In the case of the Modeling Instruction activities, the interactions take place primarily between students, although classroom interactions also occur between the instructor and groups of students and/or individual students. The discourse takes place between individual and small groups of students within the larger classroom. We contend that the differences in interaction and discourse are responsible for the variety of types of *SEO*s we observe in the Modeling Instruction environment. Further, learning not only occurs in the classroom but outside the classroom for all environments. We expect that student discourse and interaction looks similar inside and outside the classroom. The opportunities for self-efficacy experiences transfer with these activities. As a result, we hypothesize that the variety of types in *SEO*s facilitated through the Modeling Instruction classroom environment would also exist in the outside activities that the students from this environment take part in.

Finally, self-efficacy development is particular to specific tasks. In this paper we have described a variety of *SEO*s available to the students while working through tasks similar to those from the MI environment. However, these opportunities we have characterized are not simply opportunities for students to form beliefs about their capability to succeed in class. Rather, the activities that these students engage in, model development and deployment, are designed to be authentic representations of the activities of practicing scientists. As such, the *SEO*s demonstrated in this paper are not centered only on developing beliefs to succeed in a physics class, but also on beliefs about the student's ability to practice science. Thus, the variety of *SEO*s present in the activities of model development and deployment may be responsible for much more of the success that has been documented by Modeling Instruction than the impact on self-efficacy alone.

References (Chapter 5)

[1] E. Brewe, Am. J. Phys. **76**, 1155 (2008).

[2] E. Brewe, V. Sawtelle, L. H. Kramer, G. E. O'Brien, I. Rodriguez, and P. Pamelá, Phys. Rev. ST PER **6**, 0106 (2010).

[3] E. Brewe, L. Kramer, and G. O'Brien, Phys. Rev. ST PER **5**, 13102 (2009).

[4] V. Sawtelle, E. Brewe, and L. H. Kramer, in *Proceedings of the 2010 Physics Education Research Conference, Portland, 2010,* edited by C. Singh, M. Sabella, S. Rebelllo, (AIP, Melville, 2010)), p. 289.

[5] A. Bandura, Psychol. Rev. **84**, 191 (1977).

[6] K. O. Moe and A. M. Zeiss, Cognitive Ther. Res. **6**, 191 (1982).

[7] N. E. Betz and G. Hackett, J. Couns. Psychol. **28**, 399 (1981).

[8] G. Hackett and N. E. Betz, J. Vocat. Behav. **18**, 326 (1981).

[9] R. W. Lent, S. D. Brown, and K. C. Larkin, J. Couns. Psychol. **33**, 265 (1986).

[10] S. L. Britner, J. Res. Sci. Teach. **45**, 955 (2008).

[11] S. Lau and R. W. Roeser, Educational Assessment **8**, 139 (2002).

[12] S. Andrew, J. Adv. Nurs. **27**, 596 (1998).

[13] S. D. Brown, R. W. Lent, and K. C. Larkin, J. Vocat. Behav. **35**, 64 (1989).

[14] G. Hackett and N. E. Betz, J. Res. Math Educ. **20**, 261 (1989).

[15] K. D. Multon, S. D. Brown, and R. W. Lent, J. Couns. Psychol. **38**, 30 (1991).

[16] R. W. Lent, F. G. Lopez, and K. J. Bieschke, J. Couns. Psychol. **38**, 424 (1991).

[17] D. H. Schunk, Educ. Psychol. **26**, 207 (1991).

[18] A. M. L. Cavallo, W. H. Potter, and M. Rozman, Sch. Sci. Math. **104**, 288 (2004).

[19] V. Sawtelle, E. Brewe, and L. H. Kramer, Manuscript submitted for publication (2010).

[20] E. L. Usher and F. Pajares, Rev. Educ. Res. **78**, 751 (2008).

[21] A. L. Zeldin, S. L. Britner, and F. Pajares, J. Res. Sci. Teach. **45**, 1036 (2008).

[22] A. Bandura, *Self-efficacy: The Exercise of Control*, edited by S. F. Brennan and C. Hastings (W.H. Freeman and Company, New York, NY, 1997).

[23] R. W. Lent, F. G. Lopez, S. D. Brown, and P. A. Gore Jr, J. Vocat. Behav. **49**, 292 (1996).

[24] R. M. Klassen, J. Educ. Psychol. **96**, 731 (2004).

[25] T. Matsui, K. Matsui, and R. Ohnishi, J. Vocat. Behav. **37**, 225 (1990).

[26] R. W. Lent, S. D. Brown, M. R. Gover, and S. K. Nijjer, J. Career Assessment **4**, 33 (1996).

[27] M. A. Hutchison, D. K. Follman, M. Sumpter, and G. M. Bodner, J. Eng. Educ. **95**, 39 (2006).

[28] A. L. Zeldin and F. Pajares, Am. Educ. Res. J. **37**, 215 (2000).

[29] M. Hutchison-Green, D. Follman, and G. Bodner, Journal of Engineering Education **97**, 177 (2008).

[30] E. L. Usher and F. Pajares, Contemp. Educ. Psychol. **31**, 125 (2006).

[31] M. F. Shaughnessy, Educ. Psychol. Rev. **16**, 153 (2004).

[32] L. Bakken, A. Byars-Winston, D. Gundermann, E. Ward, A. Slattery, A. King, D. Scott, and R. Taylor, Adv. Health Sci. Educ. **15**, 167 (2010).

[33] V. Sawtelle, E. Brewe, R. M. Goertzen, and L. H. Kramer, Manuscript submitted for publication (2011).

[34] I. A. Halloun, *Modeling theory in science education* (Springer, Netherlands, 2006), 24.

[35] I. Halloun, J. Res. Sci. Teach. **33**, 1019 (1996).

[36] D. Hestenes, Am. J. Phys. **55**, 440 (1987).

[37] M. Wells, D. Hestenes, and G. Swackhamer, Am. J. Phys. **63**, 606 (1995).

[38] D. M. Desbien, PhD Arizona State University, 2002.

[39] J. Durden, E. Brewe, and L. H. Kramer, in *Paper presented at the meeting of the American Association of Physics Teachers, Jacksonville, FL*, 2011, (unpublished).

[40] N. J. Nersessian, Sci. Educ. -Netherlands **4**, 203 (1995).

[41] N. J. Nersessian, *How do scientists think? Capturing the dynamics of conceptual change in science* (University of Minnesota Press, Minneapolis, 1992), 15, p. 3.

[42] F. Erickson, *Ethnographic microanalysis of interaction* (Academic Press, San Diego, CA, 1992), p. 201.

[43] B. Sherin, J. Res. Sci. Teach. **43**, 535 (2006).

[44] P. D'Alessandris, *Spiral Physics*.

[45] D. Wheeler and N. Charoenkul, Phys. Teach. **36**, 274 (1998).

[46] D. Ratcliff, *Video methods in qualitative research.* (American Psychological Association, Washington, DC, 2003), p. 113.

[47] J. W. Creswell and D. L. Miller, Theor. Pract. **39**, 124 (2000).

CHAPTER 6 CONCLUSIONS

In this chapter I take the opportunity to summarize the findings from the previous chapters in reference to the research questions, discuss the implications of these findings for improving retention and persistence in physics, and explore the future directions this research avenue might take.

6.1 Summary of Findings

The focus of this dissertation is to understand the role that self-efficacy plays in retaining students, particularly women, in physics. I focus on the introductory course as it provides a gateway to the physics major, and thus success in this environment is the first step toward success in the physics major. Additionally, a focus on the introductory course provides a large number of students for investigation of the role of self-efficacy. I use a mixed methods approach to first investigate the utility of self-efficacy in predicting the success of introductory physics students, and then to investigate the development of self-efficacy. Finally, I focus on a particular course environment, and attempt to identify and describe a mechanism by which Modeling Instruction impacts self-efficacy, leading to the success of students in the class. Here, I summarize the major findings of our studies, organized by the research questions that guided the work.

6.1.1. The Role of Self-Efficacy in Retaining Students

1) What role does self-efficacy play in retaining students in introductory physics?

Chapter 2 sets out to understand the predictive power of self-efficacy for the success of introductory physics students. I use a sequential logistic regression technique to first examine the utility of including self-efficacy in a model predicting student success in the Introductory Physics with Calculus I course. I find that self-efficacy significantly improves the ability to predict the success of all students above and beyond the impact of course type and initial content understanding. The self-efficacy score yields an odds ratio of 1.4 with a 95% confidence interval on the odds ratio showing a consistent positive effect (1.1 – 1.9) on the success of all students in introductory physics.

In addition, through a disaggregation of the data by the source of self-efficacy, I find the impact of each source of self-efficacy differs for men and women. Again, through the use of a sequential logistic regression analysis predicting the success of men and women separately, I find that *mastery experiences* best predict the success of men, but *vicarious learning* experiences best predict the success of women, which is consistent with the work from Zeldin et al. [1,2]. For men the impact of the *mastery experiences* source of self-efficacy is clearly positive regardless of the course type the students were enrolled in. Extending the work of Zeldin et al., however, for women a clear positive effect from the *vicarious learning* experiences is demonstrated only when the students are also enrolled in the Modeling Instruction course.

6.1.2. The Impact of Self-Efficacy on Retention Rates in Modeling Instruction & Lecture Classes

> *2) How can self-efficacy be used to understand the improved retention rates of women in the Modeling Instruction course as compared to traditional Lecture-format courses?*

Upon learning that self-efficacy plays an important role in predicting the success of all students in Introductory Physics with Calculus I, I turn to using self-efficacy to understand the improved retention rates of women in Modeling Instruction courses over those who enrolled in traditional Lecture format courses. In Chapter 2 the sequential logistic regression analysis predicting the success of women yields information showing the impact of the *vicarious learning* source of self-efficacy is different for women in Modeling Instruction than those in the Lecture course. In the model predicting the success of women, I find a clear positive effect of the *vicarious learning* source of self-efficacy for those enrolled in the Modeling Instruction course. However, though the effect of the *vicarious learning* source for women enrolled in the traditional Lecture course is positive, the confidence on that effect size does not clearly indicate a positive relationship with success. Since the model predicting the success of all women in introductory physics shows the impact of *vicarious learning* experiences has the most predictive power for the success of women, the lack of clear positive predictive power of the *vicarious learning* experiences in the Lecture courses might provide a partial explanation of why women are more likely to succeed in the Modeling Instruction course [3].

In Chapter 3, I further investigate the differences in self-efficacy for students in Modeling Instruction and those enrolled in a traditional Lecture course. In this short chapter I address the effect of the course on the self-efficacy of students enrolled. I find that traditional Lecture instruction has a negative effect on self-efficacy for all students with an average effect size of .5, indicating the post self-efficacy scores of traditional Lecture students are half a standard deviation lower than their self-efficacy upon entering the class. On the other hand Modeling Instruction has no significant effect on the self-efficacy scores of students, which when compared with the Lecture students can be interpreted as a positive effect. Considering the results of the sequential logistic regression analysis showing the strong relationship between self-efficacy and success in the course, the differences in the effect of course type on self-efficacy in one semester may be in part responsible for the different retention rates in Lecture and Modeling Instruction courses.

In Chapter 3 I further investigated the impact of the course on self-efficacy disaggregated by gender and by source of self-efficacy. For women, the Lecture format course has a negative impact on every source of self-efficacy with effect sizes ranging from the smallest in the *physiological state* source (.045) and the largest in the *vicarious learning* source (.55). In contrast, the Modeling Instruction course has no significant effect on any of the sources of self-efficacy, except the *verbal (social) persuasion* source where it has a positive effect.

When combining the results from the shift in self-efficacy analysis with those from the sequential logistic regression, an explanation emerges for why the Modeling Instruction courses have improved retention rates for women. The initial sequential logistic regression models indicate that self-efficacy is an important predictor of success for women in introductory physics, and the shift data shows that Modeling Instruction and Lecture instruction have different impacts on self-efficacy throughout the first semester course. Furthermore, these two studies indicate that the *vicarious learning* source of self-efficacy and the *social persuasion* source are of particular interest for understanding the persistence and success of women in introductory physics.

6.1.3. How Self-Efficacy Contributes Differently to the Success of Women and Men

3) How do self-efficacy experiences contribute differently to the success of women (as an underrepresented group in physics) and men in the first semester introductory physics course?

Having shown that self-efficacy can help us understand the retention of students, especially women, in introductory physics, we turn to understanding more specifically the impact of the various sources of self-efficacy and how the impact differs for women and men. In part, Chapter 2 addresses this question with the results from the sequential logistic regression analysis. As discussed previously, the results indicate that the models that predict the success of women and men are built up by different sources of self-efficacy. The success of men is best predicted by the *mastery experiences* source, while the success of women relies on the *vicarious learning* source. However, as I use a mixed methods design for this study, I set out to further understand this result using a qualitative analysis.

The results from the qualitative analysis are discussed in Chapter 4. In this study, the goal is to understand the development of self-efficacy and in particular the sources of self-efficacy that would best help to explain the results from women in the previous study. However, what was discovered shows that a deep understanding of the development of self-efficacy requires a methodological shift from the traditional focus on recollection and memory to a focus on what happens as real-time events unfold. Chapter 4 presents this alternative methodology of analyzing for *self-efficacy opportunities* (*SEO*s) using video data instead of relying on recollected memories of events. I demonstrate in this chapter that the *SEO* framework yields important affordances that emphasis the impact of *vicarious learning* and *social persuasion* opportunities. As *vicarious learning* experiences is shown in Chapter 2 to have the most predictive power on the success of women in physics, and *social persuasion* is the only source of self-efficacy to be positively impacted by the introductory physics class in Chapter 3, it seems critical that the methodology focus on understanding the development of these two sources in particular. Chapter 4 demonstrates that an analysis of *SEO*s provides this focus, and represents a reasonable approach to understanding the development of self-efficacy.

6.1.4. Modeling Instruction and its Relation to Self-Efficacy Development

> *4) In what ways does Modeling Instruction mediate changes in self-efficacy for students?*

Some of the impacts Modeling Instruction has on self-efficacy in the introductory physics course have already been discussed in results from previous questions. Chapter 3 demonstrates Modeling Instruction has no significant impact on the self-efficacy of students in the introductory course, which when compared to the negative impact of Lecture instruction, is considered a positive result. Further, when the students are split into two separate groups Modeling Instruction has a significant positive effect on the *social persuasion* source of self-efficacy. As a result the research turns to an analysis of *self-efficacy opportunities* to determine how Modeling Instruction impacts the self-efficacy of students.

Chapter 5 discusses a microanalysis of a segment of a problem-solving session with three women enrolled in a Modeling Instruction course for evidence of *self-efficacy opportunities.* The analysis finds that Modeling Instruction affords a variety of types of *self-efficacy opportunities*. When the students engage in activities common in the Modeling Instruction environment, confidently deploying a tool from basic model and hesitantly extending the development of the tool, the activity provides a variety of types of *SEO*s. In particular, *social persuasion opportunities* and *vicarious learning* *opportunities* in addition to the *mastery experience opportunities* were found when the students engage in these two activities. When considering the results from the earlier quantitative studies, I argue that the presence of these varied types of *SEO*s provides a mechanism by which Modeling Instruction may impact self-efficacy over the course of a semester.

6.2 Implications of This Research

6.2.1. Implications for Instructors

Having discussed the major findings of this research, this section turns to discussing the implications for the persistence and retention of students in physics. In defining success of students, as instructors we can focus our attention on conceptual learning [4--6], on supporting underrepresented groups on conceptual understanding [3,7,8], by improving attitudes about what it means to learn science [9,10], or on supporting self-beliefs about ability to do physics [11]. In this work I have demonstrated that efforts to retain women in physics should in part attend to the self-beliefs students hold about their ability to do the tasks involved in physics.

In attending to these self-beliefs about ability, this works provides a model for how we can design activities in a way that we would expect to impact self-efficacy. By concentrating on creating opportunities to develop self-efficacy in the classroom, instructors can focus on providing a variety of types of experiences for all students in their classroom. Further, the analysis of Modeling Instruction has shown that it is not difficult to create environments with a medley of types of *self-efficacy opportunities*. It is possible to imagine a classroom with very few *SEO*s, where the instructor stands at the front of the room lecturing to a group of passive observers, but it is not difficult to decide how to change that scene. Introducing opportunities for students to convince one another of particular answers, would provide *vicarious learning opportunities* in addition to *mastery experience opportunities* for building a scientific argument. Alternatively, an instructor could include opportunities to work together to design and carry out laboratory experiments as in studio-based reforms [13,14], or alter companion sections of laboratories or recitation sections to incorporate group work and in-depth problem-solving [15--17].

With any of these approaches opportunities to impact self-efficacy could reasonably extend from *VLO*s and *MEO*s to include *social persuasion opportunities* to impact self-beliefs to do laboratory work or involved problem-solving. Finally, if the classroom were to include consensus-building discourse between students and instructor as well as content centered on model development and deployment, such as in Modeling Instruction [18] we would expect to see *VLO*s, *MEO*s, and *SPO*s occurring and impacting student self-efficacy to the central activities of practicing scientists.

As a result of attending to the development of these self-beliefs the expectation would be that all of these classrooms would demonstrate varying results in increasing retention rates for students in science, and particularly for those students, such as women, who draw on sources of self-efficacy that are not primarily *mastery experiences*. However, I draw attention to the point that attending to the development of self-efficacy beliefs does not imply that an instructor must choose between a “happy” class and one that demonstrates conceptual understanding and/or expert-like beliefs about learning science. In fact, the contrary appears to be true. As described above, I would expect well established reform efforts such as Peer Instruction, Investigative Science Learning

Environment (ISLE), Washington Tutorials, and SCALE-UP to all create a variety of opportunities to impact self-efficacy. At the same time, all of these curricula have been demonstrated to improve conceptual understanding [4,14,19] and/or beliefs about doing and learning science [5,16,20,21]. As a result, I argue that attending to self-efficacy should be just one more measure of success instructors consider when designing their classrooms, and improved retention rates of women will most likely follow.

6.2.2. Implications for Researchers

The implications of this study primarily lie in the methodological shift I have proposed for understanding the development of self-efficacy. As discussed in Chapter 4 of this work, the results of looking for particular types of information to impact the self-efficacy beliefs of specific groups has not led to a clear picture of how self-efficacy develops. Chapters 4 and 5 provide a way of investigating the development of self-efficacy in real-time from moment to moment. Including an analysis of *self-efficacy opportunities* in addition to reflective interviews asking what events impacted self-efficacy and surveys that elicit current self-efficacy beliefs would create a coherent model for how self-efficacy develops across time.

6.3 Directions for Future Work

Future research resulting from this project primarily centers on extending this work to new populations. All studies described in this project were completed in the environment of a Hispanic Serving Institution, and with either traditional Lecture students or Modeling Instruction students. In order to examine the generalizability of these results, I would like to see this work extended to look at different types of reform efforts in Introductory Physics such as Peer Instruction [12], and with populations that are not predominately Hispanic.

Further, within this work we have described a specific model of how self-efficacy develops through an analysis of *self-efficacy opportunities*. However, we have limited this analysis to a single group of students from a Modeling Instruction classroom. We would like to extend this study to look at a similar group from a traditional Lecture class, as well as groups from other reforms such as ISLE [13] and Peer Instruction [12], as well as to use the methodology to analyze moments in the classroom. In addition, I would like to extend the analysis of *self-efficacy opportunities* to upper-division courses in the physics major. Work from Seymour and Hewitt [22] suggest that women may choose to leave the sciences upon entering these upper-division courses, and I would like to examine the development of self-efficacy in these courses.

In this work I have developed a model for how self-efficacy develops in Introductory Physics with Calculus I course at Florida International University, with a focus on the self-efficacy development of women. I have provided a framework for analyzing the development of self-efficacy in real-time and how self-efficacy relates to success in Introductory Physics. In doing so I have provided a mechanistic framework to explain the success Modeling Instruction has demonstrated with retaining women in physics [3], and a model for how future activities may be designed to positively impact self-efficacy development and thereby the retention of women in physics.

References (Chapter 6)

[1] A. L. Zeldin and F. Pajares, Am. Educ. Res. J. **37**, 215 (2000).

[2] A. L. Zeldin, S. L. Britner, and F. Pajares, J. Res. Sci. Teach. **45**, 1036 (2008).

[3] E. Brewe, V. Sawtelle, L. H. Kramer, G. E. O'Brien, I. Rodriguez, and P. Pamelá, Phys. Rev. ST PER **6**, 0106 (2010).

[4] C. H. Crouch and E. Mazur, Am. J. Phys. **69**, 970 (2001).

[5] N. D. Finkelstein and S. J. Pollock, Phys. Rev. ST PER **1**, 010101 (2005).

[6] D. Trowbridge and L. McDermott, Am. J. Phys. **49**, 242 (1981).

[7] L. E. Kost, S. J. Pollock, and N. D. Finkelstein, Phys. Rev. ST PER **5**, 010101 (2009).

[8] L. E. Kost-Smith, S. J. Pollock, and N. D. Finkelstein, Phys. Rev. ST PER **6**, 020112 (2010).

[9] E. Brewe, L. Kramer, and G. O'Brien, Phys. Rev. ST PER **5**, 13102 (2009).

[10] K. K. Perkins, W. K. Adams, S. J. Pollock, N. D. Finkelstein, and C. E. Wieman, in *Proceedings of the 2004 Physics Education Research Conference, Sacramento, CA, 2004*, edited by J. Marx, P. Heron and S. Franklin, (AIP, Melville, 2004), p. 61.

[11] V. Sawtelle, E. Brewe, and L. H. Kramer, Manuscript submitted for publication (2010).

[12] E. Mazur, *Peer instruction: A user's manual* (Addison-Wesley, Upper Saddle River, NJ, 1997), 50, p. 68.

[13] E. Etkina and A. Van Heuvelen, Investigative Science Learning Environment – A Science Process Approach to Learning Physics (Compadre, 2007).

[14] R. J. Beichner and et al., *Introduction to SCALE-UP: Student-centered activities for large enrollment university physics* (US Dept. of Education, Office of Educational Research and Improvement, Educational Resources Information Center, Compadre, 2007).

[15]] L. McDermott and E. Redish, Am. J. Phys. **67**, 755 (1999).

[16] P. Heller and M. Hollabaugh, Am. J. Phys. **60**, 637 (1992).

[17] University of Maryland, Open-source Tutorials Integrated with Professional Development Materials, 2011.

[18] E. Brewe, Am. J. Phys. **76**, 1155 (2008).

[19] R. M. Goertzen, E. Brewe, L. H. Kramer, L. Wells, and D. Jones, Phys. Rev. ST PER (to be published).

[20] E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M. Gentile, S. Murthy, D. Rosengrant, and A. Warren, Phys. Rev. ST PER **2**, 020103 (2006).

[21] A. Karelina and E. Etkina, Phys. Rev. ST PER **3**, 020106 (2007).

[22] E. Seymour and N. M. Hewitt, *Talking about leaving* (Westview Press, Boulder, Colo, 1997).

APPENDIX 1

This Appendix includes the Survey of Self-Efficacy in Science Courses – Physics (SOSESC–P) survey given to students to evaluate self-efficacy. Immediately following the survey is a description of which items are used for calculating scores in each of the four sources categories, as well as an indication of which items were reverse scored.

SOSESC—Physics

Please indicate how strongly you agree with each of the following statements about your experiences *in this course* (including labs, if applicable.)

1. I received good grades on my assignments in this class.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

2. My mind went blank and I was unable to think clearly when working on assignments.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

3. Watching other students in class made me think that I could not succeed in physics.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

4. When I came across a tough physics question, I worked at it until I solved it.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

5. Working with other students encouraged and motivated me in this class.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

6. I have usually been at ease in this class.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

7. Listening to the instructor and other students in question-and-answer sessions made me think that I could not understand physics.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

8. I found the material in this course to be difficult and confusing.

   1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

9. I enjoyed physics labs/activities.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

10. My instructor's demonstrations and explanations gave me confidence that I could solve physics-related problems.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

11. I was rarely able to help my classmates with difficult physics problems.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

12. My instructor encouraged me that I could use physics concepts to understand real life phenomena.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

13. I usually didn't worry about my ability to solve physics problems.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

14. I had difficulty with the exams/quizzes in this class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

15. I am poor at doing labs/activities to explore physics questions.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

16. The instructor in this course encouraged me to put forth my best efforts.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

17. I rarely knew the answer to the questions raised in class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

18. Physics makes me feel uneasy and confused.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

19. I identified with the students in this class who did well on exams/quizzes.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

20. I got positive feedback about my ability to recall physics ideas.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

21. I got a sinking feeling when I thought of trying hard physics problems.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

22. I learned a lot by doing my physics assignments/activities.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

23. During this course, I admired my instructor's understanding of physics.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

24. In-class discussions and activities helped me to relax, understand, and enjoy my experience in the course.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

25. My instructor's feedback discouraged me about my ability to perform well on physics exams/quizzes.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

26. It was fun to go to this class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

27. I could relate to many classmates who were involved and attentive in class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

28. No one in class has encouraged me to go on in science after this course.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

29. I got really uptight while taking exams/quizzes in this class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

30. I can remember the basic physics concepts taught in this class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

31. Classmates who were similar to me usually had trouble recalling details taught in class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

32. My peers in this course encouraged me that I had the ability to do well on class projects/assignments.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

33. I was attentive and involved in what was going on in class.

1 Strongly disagree 2 Disagree 3 Neutral 4 Agree 5 Strongly agree

SOSESC—Physics Key

Reverse scored items are italicized.

I. Mastery Experiences (ME) 10 items

attainment

1. I received good grades on my assignments in this class.

15. I am poor at doing labs/activities to explore physics questions. ***R***

11. I was rarely able to help my classmates with difficult physicians problems. ***R***

4. When I came across a tough physics question, I worked at it until I solved it.

understanding

22. I learned a lot by doing my physics assignments/activities.

8. I found the material in this course to be difficult and confusing. ***R***

17. I rarely knew the answer to the questions raised in class. ***R***

attention

33. I was attentive and involved in what was going on in class.

test-taking

14. I had difficulty with exams/quizzes in this class. ***R***

recall & recognition

30. I can remember the basic physics concepts taught in this class.

II. Vicarious Learning (VL) 7 items

attainment

10. My instructor's demonstrations and explanations gave me confidence that I could solve physics-related problems.

3. Watching other students in class made me think that I could not succeed in physics. ***R***

understanding

23. During this course, I admired my instructor's understanding of physics.

7. Listening to the instructor and other students in question-and-answer made me think that I could not understand physics. ***R***

attention

27. I could relate to many classmates who were involved and attentive in class.

test-taking

19. I identified with the students in this class who did well on exams/quizzes.

recall & recognition

31. Classmates who were similar to me usually had trouble recalling the details taught in class. ***R***

III. Social Persuasion (SP) 7 items

attainment

32. My peers in this course encouraged me that I had the ability to do well on class projects/assignments.

16. The instructor in this course encouraged me to put forth my best efforts.

28. No one in class has encouraged me to go on in science after this course. ***R***

understanding

12. My instructor encouraged me that I could use physics concepts to understand real life phenomena.

attention

5. Working with other students encouraged and motivated me in this class.

test-taking

25. My instructor's feedback discouraged me about my ability to perform well on physics exams/quizzes. ***R***

recall & recognition

20. I got positive feedback about my ability to recall physics ideas.

IV. Physiological State (PS)9 items

attainment

13. I usually didn't worry about my ability to solve physics problems.

21. I got a sinking feeling when I thought of trying hard physics problems. ***R***

9. I enjoyed physics labs/activities.

understanding

18. Physics makes me feel uneasy and confused. ***R***

24. In-class discussions and activities helped me to relax, understand, and enjoy my experience in the course.

attentiveness

6. I have usually been at ease in this class.

26. It was fun to go to this class.

test taking

29. I got really uptight while taking exams/quizzes in this class. ***R***

recall & recognition

2. My mind went blank and I was unable to think clearly when working on assignments. ***R***

VITA

VASHTI SAWTELLE

	Born, Zanesville, Ohio
2006	B.A., Physics Grinnell College Grinnell, Iowa
2006 – 2007	Research Scientist Battelle Memorial Institute Columbus, Ohio
2007 – 2008	Teaching Assistant Florida International University Miami, Florida

Publications and Presentations

Sawtelle, V., Brewe, E., Kramer, L.H., “Creating Opportunities to Influence Self-Efficacy through Modeling Instruction,” Proceedings of the 2010 Physics Education Research Conference, AIP Press. Melville NY, (in press).

Sawtelle, V., Brewe, E., Kramer, L.H., "Positive Impacts of Modeling Instruction on Self-Efficacy," Proceedings of the 2010 Physics Education Research Conference, AIP Press. Melville NY,1289, 289-292, (2010).

Brewe, E., Sawtelle, V., Kramer, L.H., O'Brien, G.E., Rodriguez, I., Pamela, P., "Toward Equity Through Participation in Modeling Instruction in Introductory University Physics," Phys. Rev. Special Topics - PER, 6, 010106 (2010).

Sawtelle, V., Brewe, E., Kramer L.H., "An Exploratory Qualitative Study of the Proximal Goal Setting of Two Introductory Modeling Instruction Physics Students,” Proceedings of the 2009 Physics Education Research Conference, AIP Press. Melville NY,1179, 261-264, (2009).

Sawtelle, V., Brewe, E., Kramer, L., “A validation study of the Colorado Learning About Science Survey at a Hispanic-Serving Institution,” Phys. Rev. Special Topics-PER, 5, 023101 (2009).