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Pedagogical Effects on Student Learning, Attitude, and Retention of Physics Majors

Zeynep Topdemir

PEDAGOGICAL EFFECTS ON STUDENT LEARNING, ATTITUDE, AND RETENTION OF PHYSICS MAJORS

by

ZEYNEP TOPDEMIR

Under the Direction of Brian D. Thoms, PhD

ABSTRACT

This dissertation aims to improve physics education by evaluating instructional interventions in introductory physics courses and retention decisions of physics majors. Physics Education Research Group at Georgia State University (GSU) has implemented two instructional interventions in introductory physics courses: SCALE-UP implementation in algebra-based courses and lab reform in calculus-based courses. Half of the algebra-based courses at GSU has converted as SCALE-UP in Fall 2008. The effects of implementation on student learning, retention, and learning attitudes are investigated. It has been found that student learning and retention are improved in SCALE-UP, but Traditional courses have caught up this improvement over the years. Since the same instructors teach both courses, instructors started to use research-based interactive methods in both classes and may result in these improvements in both of them over the years. However, only SCALE-UP is effective in improving students' attitudes and beliefs in Conceptual Understanding and Problem-Solving categories. We suggest that instructor involvement in all aspects of the course results in a more coherent expert-like framework presented in SCALE-UP classrooms resulting in the development of a more integrated expert-like view of Conceptual Understanding and Problem Solving.

Three-hour traditional labs converted into one-hour tutorials with learning assistants, and two-hour inquiry-based experiments with lab reform. The effects of lab reform on student learning, persistence, and learning attitudes are investigated. We report lab reform improved student learning and retention rates but fail to improve learning attitudes. Even though lab reform is successful in increasing students' conceptual understanding and result in improvements in learning and retention, students report they do not see tutorials as a practical use of time and energy may be resulting in negative learning attitudes.

Moreover, to improve physics education, we have investigated the characteristics of students who stayed in physics by interviewing with undergraduate physics majors from first-year students to seniors. Their experiences, physics identity development, and integration into the physics department are probed. We have found that Gateway to Physics Courses, upper-level physics courses, and doing research are significant milestones that influence students' persistence decisions by influencing physics majors' identity and academic integration.

INDEX WORDS: PER, SCALE-UP, lab reform, retention, physics identity, integration

PEDAGOGICAL EFFECTS ON STUDENT LEARNING, ATTITUDE, AND RETENTION OF PHYSICS MAJORS

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ZEYNEP TOPDEMIR

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by

ZEYNEP TOPDEMIR

Committee Chair: Brian D. Thoms

Committee: Kadir Demir

Megan Elizabeth Connors

Michael Schatz

Mukesh Dhamala

Electronic Version Approved:

Office of Graduate Studies

College of Arts and Sciences

Georgia State University

July 2020

DEDICATION

I would like to dedicate this dissertation to my family, especially my mom, dad, and siblings, who always supported me. Also, I would like to dedicate this work to my advisor, and my friends, who always supported me in the process of this dissertation. I would not have done this without their support. Moreover, I would like to dedicate this dissertation to all women in the world who fight for their rights.

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1 INTRODUCTION

The National Academies Board reported in 2007 that only one of the seven students who get a degree in the United States receive a degree in science, technology, engineering, and mathematics (STEM) compared to one in two students in China and one in three in Singapore [1]. The National Science Foundation (NSF) identified low rates of STEM degree productions as a threat to the country's ability to compete in a global economy [1]. For these reasons, NSF raised attention to reform every aspect of STEM teaching and learning. One of the reasons why STEM produces fewer degrees than other fields is low retention rates. Only 63.7% of the students who begin to major in science and engineering fields (S&E) stayed in S&E, and 12.9% of them earned their degree in a different S&E field than they started according to NSF 2012 report [2, 3]. In this dissertation, retention in courses were studied and how different teaching interventions affect retention rates for the courses was measured. However, retention in STEM majors has been studied by a few researchers [2, 3, 4]. Universities mostly report their retention rates, but they generally do not specify retention rates separately for each major. That is why it is hard to get exact retention rates in physics. According to the NSF 2012 report, physical and mathematical sciences have lower retention rates compared to other STEM majors like biological sciences. Therefore, the goal of this dissertation is to understand students' persistence decisions.

Students' persistence decisions are closely related to their performance, attitudes and beliefs [5, 6]. At the course level, students' performance and learning in that course influence their attitudes and beliefs about learning physics. Thus, students' learning and attitudes affect persistence decisions in that course [5, 6]. Students' persistence decisions in a major are also affected similarly by their performance and attitudes about learning. It has been reported that students mostly change their major in the first two years of college when they take other classes [7, 8]. Students discover their interest in other majors in the first two years, and because of that, they change their majors. Therefore, the goal of this dissertation is to investigate students' persistence decisions both in the physics program but also at the course level. Not only the effects of different instructional methods of the introductory physics courses on students' attitudes and persistence decisions were measured, but also attitudes and persistence decisions of physics majors at the program level were investigated to develop physics education.

In general, Physics Education Research (PER) studies how students learn physics and investigates ways to improve learning physics. PER consists of two main branches: researching instructional methods and methodologies and investigating students' developments. The aim of this dissertation is to investigate relations between student attitudes and persistence decisions both at the course level and program level at Georgia State University (GSU) and by contributing to PER to motivate others to explore more about student attitudes and retention.

PER uses both qualitative and quantitative research methods depending on the goal of the study. PER researchers use different quantitative research methods. One of the frequently used quantitative methods is developing standardized tests to measure the effectiveness of the instructional interventions. Standardized tests, such as conceptual learning assessments, might have various goals like measuring the effect of instructional interventions on students' learning. Standardized tests can also measure the effect of interventions on students' mental development like self-efficacy, growth mindset, and epistemological beliefs about science assessments. Using quantitative methods is not enough if the goal of the study is not just to measure the effectiveness of interventions but also to understand how the intervention is effective and what components of intervention contribute to its effectiveness and how. To investigate deeper how the intervention affects participants or institutions, PER uses qualitative methods like those used in social sciences. In addition, researchers use qualitative methods when they do not have a large enough number of participants to prove the significance of their intervention with standardized tests. Qualitative methods vary depending on the goal, framework, and settings of the study. Different types of interviews, such as focus or subject interviews, are used in qualitative research. In this research, both qualitative and quantitative methods were used and analyzed.

The second chapter of this dissertation focuses on investigating the first branch of the PER, evaluates one of the instructional renovations at GSU, the implementation of Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP) in algebra-based classrooms [9]. SCALE-UP, a technology-rich studio physics model (integrated lecture and lab) developed by North Carolina State University, is designed to increase interaction between students and instructors and is effective in large-enrollment classrooms. The physics department of GSU converted half of the algebra-based classes as SCALE-UP beginning in Fall 2008. In SCALE-UP, students sit at round tables, which promotes group discussions.

In this chapter, quantitative research methods are used to measure the effectiveness of the SCALE-UP classrooms and compare them with traditional courses. In the last decade, there is attention toward investigating the epistemological views of students. It has been shown that attitudes and beliefs toward learning science/physics both influence students' learning also affect their decisions to stay in the same major [5]. Therefore, I have investigated students' attitudes and beliefs about learning physics in SCALE-UP classrooms by using the Colorado Learning Attitudes about Science Survey (CLASS) and compared with the traditional courses [10]. CLASS measures students' attitudes and beliefs about learning physics and compares those with expert physicists' views. By giving this assessment test as a pre- and post-course measurement, the effect of the course types on students' epistemological views about physics can be measured.

Moreover, retention is strongly correlated with students' performance [11]. Thus, students learning was investigated in SCALE-UP courses. In PER, several assessments have been developed to measure students' learning through courses [12]. The Force Concept Inventory (FCI) is used to test students' learning in SCALE-UP intervention in this dissertation [13]. These assessments were given both at the beginning and end of the courses to measure how much students learned throughout the course. Hake, 1998 compared FCI results from 62 different introductory courses, and he reported that courses with interactive engagement components were more effective for students to learn conceptually and had almost twice learning gains than traditional classes [14]. Half of the algebra-physics courses at GSU were taught as SCALE-UP, and the rest of them taught in traditional format. The students' learning of SCALE-UP courses was calculated and compared with the traditional classes. Also, the retention rate of SCALE-UP and Traditional courses were compared by calculating the rate of students who receive grades of D and F or withdraw the courses (DFW rates).

Research questions for Chapter 2 are:

1. How does SCALE-UP intervention influence students' learning, students' persistence decisions, and attitudes and beliefs about learning physics?
2. How were students' persistence decisions and attitudes related at the course level with SCALE-UP intervention?

After implementing SCALE-UP in algebra-based introductory courses at GSU and seeing positive effects, the Physics Education Research Group decided to do some redesign in the calculus-based introductory classes as well. Since implementing Washington tutorials has been reported to improve the conceptual learning of students, the PER group at GSU converted the three-hour traditional laboratory portion of calculus-based courses into one-hour tutorials with learning assistants and two-hour inquiry-based experiments [15, 16]. The third chapter focuses on measuring the effects of lab reform on retention and student attitudes.

Using inquiry-based experiments in STEM has been popular in the last decade, and various studies reported positive impacts of inquiry-based labs [17, 18, 19]. Confirmation of theory style labs were converted into more inquiry-based experiments. Prediction questions are added with revisit questions in the discussion section to encourage students to think about the hypothesis and the results they found at the end. Prediction questions are used in other published physics labs and reported positive effects [20, 21]. The level of inquiry of lab reform is measured by using a rubric developed by Buck *et al.* [22]. In the third chapter, retention rates, students' conceptual learning, and attitudes and beliefs about learning physics are investigated quantitatively and compared with before the lab reform by using FCI and CLASS assessments [10, 13].

Research questions for Chapter 3 are:

1. How does lab reform influence students' learning, students' persistence decisions, and attitudes and beliefs about learning physics?
2. How were students' persistence decisions and attitudes related at the course level with lab reform intervention?

The second and third chapters focus on evaluating interventions implemented in introductory physics classrooms and investigate the effects of these interventions on student learning, retention rates, and learning attitudes. The impacts of each intervention with its limitations are discussed. On the other hand, the fourth chapter has a different approach than the previous chapters. Instead of evaluating retention and student attitudes at the course-level, in the fourth chapter, I aim to investigate retention and attitudes at the program level by focusing on understanding the physics majors' persistence decisions. Since the number of physics majors at GSU is not enough to get significant results with assessment tests, qualitative methods are used in this chapter. In the fourth chapter, I aim to characterize the students who stayed in physics and understand their career choices. By doing this, I aimed to investigate the critical milestones in the physics majors' careers that affected their decisions to stay in physics. Physics majors from freshman to senior were interviewed for this part of to study. Students' experiences and career decisions were examined to understand persistence choices.

Research questions for Chapter 4 are:

1. What are the characteristics of students who stayed in the physics program?
2. Which experiences or activities influenced students' physics identity, their career choices like plans after graduation, or stay in physics?
3. What are the differences or similarities of physics majors at a different stage of the program?

The main goal of this dissertation is to understand the relationships between students' attitudes and retention. The answers to each chapters' research questions will help to understand retention and students' attitudes both at the course level and program level.

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2 LONGITUDINAL EXAMINATION OF SCALE-UP INTERVENTION IN ALGEBRA-BASED INTRODUCTORY PHYSICS CLASSROOMS

2.1 Introduction

There is a gap between what instructors teach and what students learn [1, 2]. Researchers have found that this gap can be decreased when students interact more with their instructors, collaborate with their peers, and learn more conceptually [1, 2, 3, 4, 5]. Researchers have developed various learning environments such as studio physics [6], TEAL [7], and SCALE-UP [8] and techniques to have a more interactive and collaborative environment and improved conceptual understanding. However, addressing only success and learning in physics classrooms is not enough. Instructors also need to address students' epistemological views. In recent years, Redish *et al.* have shown that when students see physics as coherent knowledge related to other fields and the real-world, they learn more. [9]. Almost half the algebra-based introductory physics courses have been converted as Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP) classrooms. This chapter presents the effects of SCALE-UP implementation on conceptual learning, learning attitudes and beliefs, and retention rates.

Seeing physics as a coherent knowledge is easy for experts, but for students, it is not that easy [9]. When students do not see physics as a coherent knowledge, they do not usually understand as a whole and cannot see the relation with other fields and the real world when they are learning. When they do not understand physics as a whole, they just try to memorize equations and definitions. In this case, when they are asked different types of questions, they mostly fail to answer these novel questions, which are different than they used to. Previous studies demonstrate that these beliefs and attitudes about learning physics are a better predictor of success in science than previous physics and math knowledge [9, 10, 11]. That is why, in recent years, researchers have started to give more importance to investigating these beliefs and developed several instruments, MPEX [12], VASS [13], EPABS [14]. Adams *et al.* have developed a survey called Colorado Learning Attitudes about Science Survey (CLASS) to measure students' attitudes and beliefs about physics and learning physics by building upon existing surveys [15]. Studying epistemological views is not just measuring whether students like physics or not. By measuring students' beliefs and attitudes about physics and learning physics, researchers aim to learn how students think about physics, such as whether they see physics as coherent knowledge related to the real-world or as disconnected pieces of information that must be memorized or whether students see physics as knowledge applicable to other fields or not.

Researchers discovered that students' attitudes and beliefs shape and are shaped by the instructional experiences [9, 10, 13, 16]. CLASS is a recently developed instrument has become a widely used assessment to measure the effect of different instructional experiences on students' attitudes and beliefs about physics and learning physics, distinguishes them from experts and classifies them as either expert-like or novice-like [15]. Previous research has shown that after traditional one or two-semester introductory physics instruction, students become more novice-like or remain the same [9, 11, 15, 17, 18, 21]. Instead of helping students to see physics as coherent knowledge explaining the real world, traditional introductory physics instruction often results in more novice-like attitudes and beliefs. Recently, some researchers reported a positive shift in students' expert-like attitudes with transformed instructions [19, 20, 22, 18].

To address improving conceptual learning and improving students' attitudes and beliefs about physics, the PER group at Georgia State has implemented SCALE-UP in algebra-based physics courses [8]. In SCALE-UP classrooms, instructors and teaching assistants (TA) are present in all parts of the course. Students work together at round tables, on whiteboards, and in the experiments. The nature of SCALE-UP improves the interactions between students and instructors and collaboration within students in all parts of the course. Previous studies show that SCALE-UP classrooms enhance conceptual understanding and students' learning attitudes and beliefs about physics. With SCALE-UP intervention, PER group aims to improve conceptual understanding and epistemological views of students by promoting student-centered instruction and active learning.

Half of the algebra-based physics courses were converted to a SCALE-UP format. The other half remained in the traditional format as a lecture and separate lab. The FCI was used to measure conceptual learning and compare the effectiveness of SCALE-UP and traditional format. Expert-like learning attitudes and beliefs were also investigated with CLASS in these two different classroom formats. The aim of this work is to measure the effects of SCALE-UP on persistence, conceptual learning and learning attitudes and beliefs about learning physics.

2.2 Settings/Intervention

Georgia State University (GSU) is a diverse urban public research university, located in downtown Atlanta, Georgia. GSU offers 250 undergraduate and graduate degrees in more than 100 fields of study. The student body at GSU is 38% African American, 37% Caucasian, 13% Asian, and 12% other ethnicities [23]. Thus, GSU plays a significant role in improving diversity for STEM and particularly physics majors. Moreover, GSU does not offer an engineering degree.

Biology majors and pre-med students are required to take a two-semester algebra-based physics course sequence. Non-science majors may also elect to take this course to meet science requirements. SCALE-UP was adopted in almost half of our algebra-based introductory physics classrooms beginning in Fall 2008. The other half are taught as a traditional lecture and a separate lab format. In this work, these two formats will be named as SCALE-UP and Traditional. Data was collected from the only first course (mechanics) of two-semester sequence algebra-based introductory physics classes.

Traditional courses consist of three hours of lecture and two hours of laboratory per week. The class size of lectures was no more than 60, and the size of the laboratory sections was limited to 24. The lab portion was taught by teaching assistants (TA). Instructors were responsible for the lecture part and TAs guided the lab portion. There was almost no interaction between TAs and instructors. There were pre-quizzes every week in the lab that include questions about previous lab and preparation questions about the following experiments. After the quiz, students completed hands-on experiments during the lab time. There was no homework for the lab portion.

In the SCALE-UP classrooms, lecture and laboratory portions of the course were integrated. The class met five hours per week in a room with round tables, computers, and whiteboards. The presence of round tables makes it easier to work as a group and improves collaboration between groups. Also, this structure helps instructors and TAs to go around and interact with all students more efficiently. Instructors and TAs were present in all parts of the course. There were typically only short lectures in SCALE-UP. Mostly, students were working together on questions, concepts, and experiments and discussing with their instructors and TAs. Almost every week, they also completed hands-on experiments. Different than the Traditional courses, in SCALE-UP instructors were often present during this lab activity. Each instructor created his/her own lab manuals. SCALE-UP classes had a capacity of 54 students.

Four instructors taught SCALE-UP classes during the time of this study. These instructors also taught the same courses in the traditional format. A few instructors taught courses in only the traditional format.

2.3 Methods

Conceptual learning was measured with FCI, which is multiple-choice conceptual test measures Newtonian mechanics and kinematics [24]. Hestenes *et al.* developed FCI which is one of the most commonly used instruments that measure conceptual learning in physics [24]. Students' attitudes and beliefs about physics and learning physics were measured with CLASS [15]. CLASS was developed and validated by Adams *et al.* at the University of Colorado [15]. It consists of 42 statements that students respond to them either agree or disagree on a five-point Likert-scale. An individual favorable score for a student is calculated by comparing student's agreement with experts' responses. By averaging the percentage agreement of all students, an overall favorable score and sub-scores in eight categories of attitudinal shifts of a class or reform can be calculated. CLASS categories are Personal Interest, Real-World Connection, Problem-Solving Confidence, Problem-Solving Sophistication, Sense-Making/Effort, Conceptual Understanding, Applied Conceptual Understanding [15]. CLASS probes students' attitudes and beliefs about physics and learning physics and distinguish them from experts' views.

One statement (statement number 31) is used to determine the students who are not reading the survey carefully and disregard these answers from the analysis. Favorable shifts were calculated by using matched data obtained from students who responded to the survey both in the beginning and at the end of the course used as pre- and post- scores. Since analysis required matched data, the answers from the students who skip the survey either at the beginning or at the end of the semester were not included. Also, responses from the students who answer statement number 31 incorrectly were disregarded. Because of these conditions, participation rate for the study was 60%.

Data in this paper is collected from the first semester of the two-semester sequence of algebra-based introductory physics. They contain mechanic topics such as kinematics and Newton's laws but not waves. For traditional algebra-based introductory physics courses, in the first week and the last week of the semester, FCI and CLASS were given during the laboratory session. For SCALE-UP, FCI and CLASS are given during the class hours. Data collected for this study was collected from the students who consent to participate in this study. This study was approved by the instructional review board. In algebra-based SCALE-UP classrooms, the same steps were followed. Students completed the FCI in a classroom environment with the presence of an instructor or TA. In this study, FCI and CLASS data was used only from the students who consented to study.

2.3.1 Examination of the Level of Inquiry of Labs of Traditional and SCALE-UP Courses

A rubric to characterize the labs of Traditional and SCALE-UP classrooms and measure the level of inquiry in these labs was created based on the work of Buck *et al.* [25]. In their study, they separated the experiments into six parts: problem/question, theory/background, procedures/design, result analysis, results communication, and conclusions. Then, they determined the level of inquiry based on which parts were given in the manual as step-by-step instructions and which of them were left to students to figure out themselves as shown in Table 2.3.1. If the manual provided information about that section, then it was characterized as manual provides (MP). If it was provided in a way that students figured out that section by themselves like answering questions, then it is characterized as students determine (SD). Based on Buck *et al.*, when a lab has more parts left for students to figure out, then the inquiry level of that lab is increasing, as shown in Table 2.3.1. They also found that most labs used in introductory physics labs fell between level ½ and level 1 [25]. Only undergraduate research experiences in which at least one semester is dedicated to doing the same experiment were between level 2 and level 3. Because these experiences were the places where students decided the design for their experiments completely themselves. The rubric used in our study was built based on this work but modified to ask several questions to determine which inquiry elements were present in each part of a lab. The rubric is given in Appendix A. Three different people applied the rubric for each lab. Five labs from each course were evaluated with this rubric to generalize the characterization.

Table 2.3.1 1 Rubric developed by Buck et al. [25] to characterize the inquiry level of the labs (Terminology is different than original work). MP: Manual provides, SD: Students determine.

Characteristic	Level 0: Confirmation	Level ½: Structured Inquiry	Level 1: Guided Inquiry	Level 2: Open Inquiry	Level 3: Authentic Inquiry
Problem/Question	MP	MP	MP	MP	SD
Theory/Background	MP	MP	MP	MP	SD
Procedures/Design	MP	MP	MP	SD	SD
Results analysis	MP	MP	SD	SD	SD
Results communication	MP	SD	SD	SD	SD
Conclusion	MP	SD	SD	SD	SD

Table 2.3.1 2 Comparison of characterization of the labs of the Traditional and SCALE-UP courses.

Algebra-Based Reform	**Traditional Course**	**SCALE-UP**
Problem/Question	MP	MP
Theory/Background	MP	SD
Procedures/Design	MP	Mostly MP
Results Analysis	Mostly MP	SD

Results communication	SD	SD
Conclusion	SD	SD

It was found that experiments of the lab portion of Traditional courses were mostly traditional and, as shown in Table 2.3.2. Most of the sections of lab manuals of Traditional courses were given with step-by-step instructions like a cookbook recipe in the manual except for results analysis and conclusions sections. In those sections, there were questions to help students to figure out how to analyze and summarize/interpret the data themselves. Having inquiry elements in those last two sections shows, according to Table 2.3.1, the lab portion of the Traditional course can be characterized as Level ½ Structured inquiry. Also, the lab manuals from the SCALE-UP were characterized, as shown in Table 2.3.2. Generally, the problem/question section was stated in the SCALE-UP manuals. Mostly, theories of the background of the experiment were asked through prediction questions. By working on these prediction questions, students figured out the background of the experiments. Since students explore this section by themselves, it was characterized as SD.

Procedures/Design section was provided in some of the labs of SCALE-UP. In some labs, even though there were some step-by-step instructions in this section, some significant conceptual choices were left to students to figure out themselves, or sometimes students were asked to design some parts of the experiment. Results analysis and conclusions sections were again given with questions like comparisons with prediction questions to analyze and conclude their results themselves. According to Table 2.3.1, most SCALE-UP experiments fell into the category of Level 1 Guided inquiry. Some experiments with designing parts were categorized somewhere between Level 1 Guided inquiry and Level 2 Open inquiry. Since the lab portion of Traditional courses was found as less inquiry-based than SCALE-UP, the labs of Traditional courses were redesigned in Fall 2018. The data from this redesigned version was not included in this study.

The original aim of this study was to measure the effects of SCALE-UP classrooms in algebra-based settings on conceptual learning, students' attitudes, and success rates and compare these results with traditional classrooms. Also, the aim of this study was to figure out the relationship between conceptual learning and students' expert-like beliefs about physics. The first part of the study used a four-year data set between Fall 2013 and Spring 2017 because CLASS data was only have acquired since fall 2013.

2.4 Results

2.4.1 Results from four-year matched data

Data in this part contains matched FCI and CLASS data. CLASS was administered at GSU since Fall 2013, that is why data in this part was taken between Fall 2013 and Spring 2017. Data does not include students who did not take any FCI pre/post assessment test, or CLASS pre/post survey or the ones who did not consent to the study. Thus, the total number of participants in this study is less than the total number of students who enroll in the both classroom types.

Figure 2.4.1.1 shows the CLASS pre favorable results of algebra-based introductory physics classrooms averages between Fall 2013 and Spring 2017. CLASS pre results of both Traditional and SCALE-UP classrooms are similar to each other (56.9 and 57.8 respectively), slightly lower than developers of CLASS (63 in algebra-based classrooms) and slightly higher than PET and PSET classrooms (54) which are lowest in the literature [19]. There is no statistical difference between CLASS pre scores of Traditional and SCALE-UP. Having similar CLASS pre scores means students have similar incoming learning attitudes toward physics in both classroom types. Furthermore, CLASS pre scores of Traditional and SCALE-UP courses are similar to other findings reported in literature which shows that these students come to physics classes with similar learning attitudes as other universities.

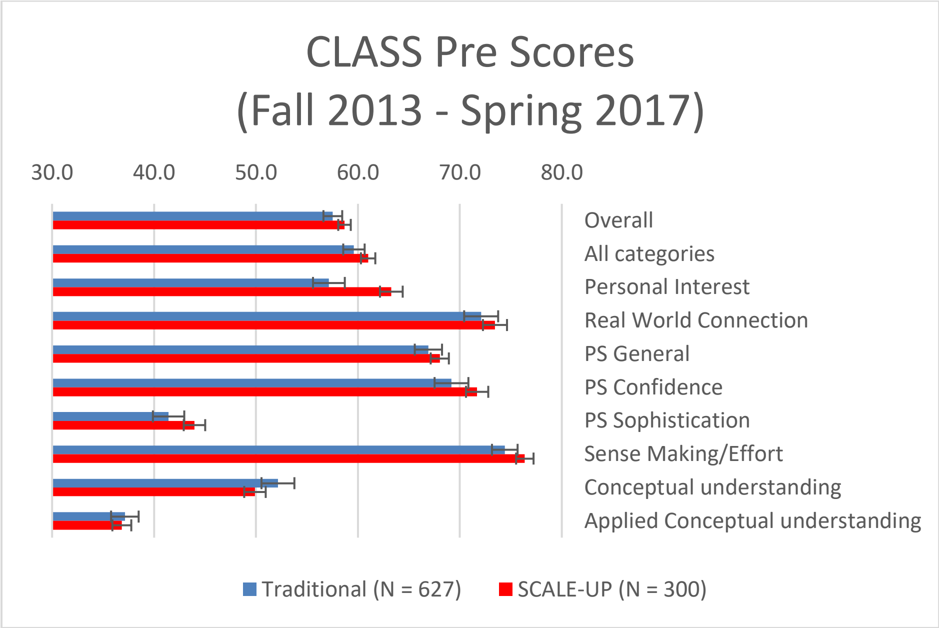

Figure 2.4.1 1 CLASS Favorable Pre results of Traditional and SCALE-UP classrooms. Error bars indicate Standard Error of the Means.

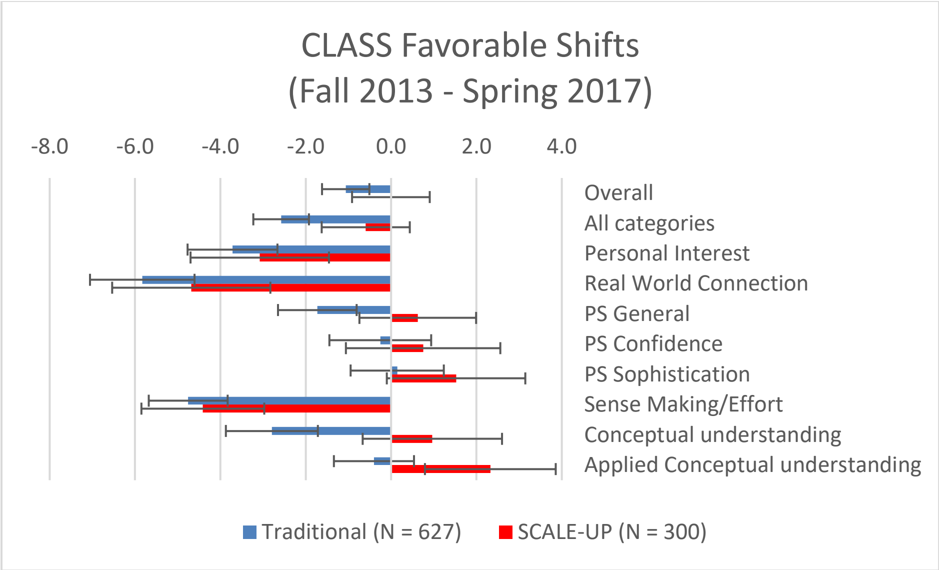

Figure 2.4.1 2 CLASS favorable shifts from Traditional and SCALE-UP classrooms between Fall 2013 and Spring 2017. Error bars indicate Standard Error of the Means.

Figure 2.4.1.2 shows shifts of CLASS favorable results for each classroom type, which was calculated by finding how each student's learning attitudes changed over the course, and then all averaging the shifts. For CLASS learning attitudes, the testing significance of shifts was essential. The significance of shifts allowed us to determine whether the change in students' learning attitudes over the semester was significant or not. In SCALE-UP classrooms, positive shifts in expert-like attitudes were found in five sub-categories of CLASS, Problem-Solving, and Conceptual Understanding categories, as well as in overall learning attitudes. However, independent t-test shows that there was no significant change in expert-like learning attitudes over SCALE-UP classrooms.

On the other hand, shifts were bigger than the standard deviation and such shifts have been claimed as significant by developers of CLASS. Only applied conceptual understanding favorable shift was significant for SCALE-UP classrooms over these two-year data. In traditional classrooms, all the learning attitude shifts were negative and the shifts in Personal Interest, Real-World Connection, Sense-Making/Effort, and Problem-Solving General categories were found to be significant.

I have also compared the shifts of traditional and SCALE-UP classrooms to see whether SCALE-UP classes influence students' learning attitudes more positively than Traditional classrooms. The Independent t-test was used to test the difference between the shifts of these two classroom types. It was found that favorable shifts were significantly different in overall ($p < .01$) learning attitudes and in four sub-categories, Problem Solving Sophistication ($p < .05$), Problem Solving Confidence ($p < .05$), Conceptual Understanding ($p < .05$), and Applied

Conceptual Understanding ($p < .01$). These show that SCALE-UP classrooms can affect students to develop more expert-like learning attitudes than Traditional classrooms do.

Negative shifts in learning physics attitudes are typical in literature [9, 11, 15, 17, 18, 21]. Developers of CLASS have found the shift over Traditional instruction in algebra-based classrooms as a -9.8 [9]. However, some studies report positive shifts in expert-like attitudes like Modeling Instruction [20], Physics by Inquiry [26], and PET curriculum [19]. Otero and Gray claim that they do not know why they observe positive shifts in the PET curriculum or whether it may be due to the emphasis on conceptual understanding or epistemological learning [19]. Brewe *et al.* claimed that positive shifts of Modeling Instruction, Physics by Inquiry and PET curriculum are due to their emphasis on implicit or explicit attempts at epistemological learning in those classrooms [20]. They suggest that working on scientific models in Modeling Instruction classrooms and students' efforts to explain these scientific models led to improvements in their scientific thinking and gave result in positive shifts in students' learning attitudes. SCALE-UP classrooms do not include implicit or explicit attempts in epistemological learning. Even though SCALE-UP has an emphasis on conceptual understanding, the reason for positive shifts in SCALE-UP is not an emphasis on conceptual understanding. It may be due to the coherent nature of SCALE-UP that might help students to see physics as a coherent knowledge and help them to gain more expert-like attitudes since Traditional classes at GSU also had an emphasis on conceptual learning, but did not yield positive shifts.

Previous positive shifts in literature also suggest that these positive shifts in students' attitudes can be due to small size classroom environments [18, 26]. However, SCALE-UP was a large enrollment class. This supports our claim that SCALE-UP although classrooms were large, students had more opportunities to interact with instructors with more active learning activities, and this may have resulted in students connecting conceptual understanding and problem-solving.

Table 2.4.1 1 FCI pre, FCI post, and normalized gains from Traditional and SCALE-UP courses between Fall 2013 and Spring 2017, Independent t-test statistics, and Cohen's d calculations are shown.

	FCI Pre (%)	FCI Post (%)	< g >
Traditional (N=627)	25 (1)	50 (1)	0.33 (0.01)
SCALE-UP (N=300)	24 (1)	51 (1)	0.36 (0.01)
t(one tail), *p* value	$t\ (563) = 0.24$ $p = 0.405$	$t\ (584) = -1.28$ $p = 0.100$	$t\ (926) = 1.92$ $p < 0.05$
Cohen's d (C.I)	0.017	0.090	0.136

$$g = \frac{\text{posttest} - \text{pretest}}{100 - \text{pretest}}$$

Figure 2.4.1 3 Normalized gain equation.

FCI results from SCALE-UP and Traditional courses are shown in Table 2.4.1.1. FCI pre scores in Traditional and SCALE-UP classrooms were 25% and 24%, respectively. There was no significant difference between FCI pre scores. Students in both classrooms had similar background conceptual knowledge about Newtonian physics. FCI post scores are 50% and 51% in these classrooms. Normalized gain (g) is calculated for each person by using the equation shown in Figure 2.4.1.4. Students' normalized gain scores were averaged to calculate a course score. Normalized gains of Traditional and SCALE-UP classrooms were 0.33 and 0.36, respectively. T-test showed that there is no significant difference in FCI post scores and normalized gains of Traditional and SCALE-UP classrooms. Both classroom types resulted in similar conceptual learning gains.

Nationwide Hake's 6000 students study shows that students can learn more conceptually in interactive engagement environments [27]. Hake defines 0 – 0.3 is low for normalized gains, 0.3 – 0.6 as medium, 0.6 – 1 as high. He found that gains of Traditional classrooms are in low range, and interactive classrooms are in medium and high range. According to this, the average normalized gains of Traditional and SCALE-UP classrooms are in the medium range. Recent studies on various studio settings such as Modeling Instructions [20], PET curriculum [21] with classic studio and SCALE-UP [28, 8] settings support Hake's findings that when there is an interactive engagement, students learn more. Even though the average of both classrooms is in a medium-range, our findings do not support these previous studies since the average normalized gain of SCALE-UP was not higher than Traditional classrooms. Our normalized gains were lower than other studio settings like Modeling Instructions [20], PET curriculum [21], and developers of SCALE-UP [8], but all of these SCALE-UP findings are from calculus-based settings. Since the results in this study have taken from algebra-based classrooms, it is normal to have lower learning gains in algebra-based settings [27].

According to Hake's study, a 60% score in the FCI is considered the threshold of understanding the Newtonian physics needed for successful problem-solving [27]. Even though average FCI post scores of Traditional and SCALE-UP classrooms are less than this limit, in Traditional and SCALE-UP classrooms at GSU, the percentages of students who exceed this limit was found as 26% and 38%, respectively. The previous study reports this number as 5% for Traditional, 22% for lectures with peer instruction, and 46% for SCALE-UP in calculus-based introductory physics classrooms. In traditional classrooms, 6% of students scored worst in the post-FCI than pre-FCI. 8% of students scored worst in the post-FCI than pre-FCI or got the same score in Traditional classrooms. In SCALE-UP, 5% and SCALE-UP of students scored worst in the post-FCI than pre-FCI. 7% of students who scored worst in the post-FCI than pre-FCI or got the same score in SCALE-UP classrooms. All these results show that Traditional and SCALE-UP courses have similar conceptual learning, and it has been suspected that there might be some level of interactive engagement in Traditional classrooms as well. Hence, PER group has decided to construct an instructor survey to examine the structure of both Traditional and SCALE-UP classrooms and figure out the similarities and differences in both classroom types.

2.4.2 Examination of the Structure of Traditional and SCALE-UP classrooms with Instructor survey

Analysis of a four-year data set show that Traditional and SCALE-UP classrooms have similar conceptual learning gains. Our hypothesis for the explanation of this similarity is since the same instructors teach both classroom types, they might have applied similar active learning strategies in both classroom types. To investigate the differences and similarities of both classes, I have built a survey by starting with Henderson and Dancy's survey about research-based instructional strategies [29]. The instructor survey is attached in Appendix B. GSU's intuitional review board reviewed this study. Data was collected from the instructors who teach Traditional and/or SCALE-UP classes and consented to participate in the study.

One of the similarities in both classrooms is that instructors supported their traditional lecturing with a discussion of the conceptual problem or solving a quantitative problem. One of the differences is that while all instructors reported that there were discussions by students within groups on solving conceptual or quantitative problems in every class, only half of the instructors reported they have these discussions in every class time. The other difference is all instructors in SCALE-UP gave graded-worksheets almost every week that students work on together. On the other hand, only half of the traditional instructors used worksheets in their classrooms. Another finding is that every SCALE-UP instructor and more than half of the traditional instructors reported that they asked conceptual questions on their exams/tests/quizzes.

These results show that Traditional classrooms of GSU were not entirely traditional. More than half of the instructors used active learning strategies in their classrooms, too. Also, conceptual learning was emphasized in both classroom types by not only working on conceptual problems but also asking conceptual questions in the assessments. The presence of interactive learning and emphasis on conceptual learning may have resulted in these similar learning gains and success rates in both classes.

2.4.3 Longitudinal Results of SCALE-UP Implementation

Table 2.4.3 1 Enrollment numbers of Traditional and SCALE-UP.

	Traditional	**SCALE-UP**
Fall 2008 - Spring 2015	3922	2024
Fall 2013 - Spring 2015	805	390

Table 2.4.3.1 shows the enrollment numbers of Traditional and SCALE-UP courses and is used when retention rates are reported as DFW rates which measure the percentage of students who start the course and withdraw or receive a grade of D or F preventing them from continuing to the next course in the sequence. I want to note that since students who did not consent for the study and who do not have matched data are not included, the total number of FCI and CLASS results are not the same as enrollment numbers.

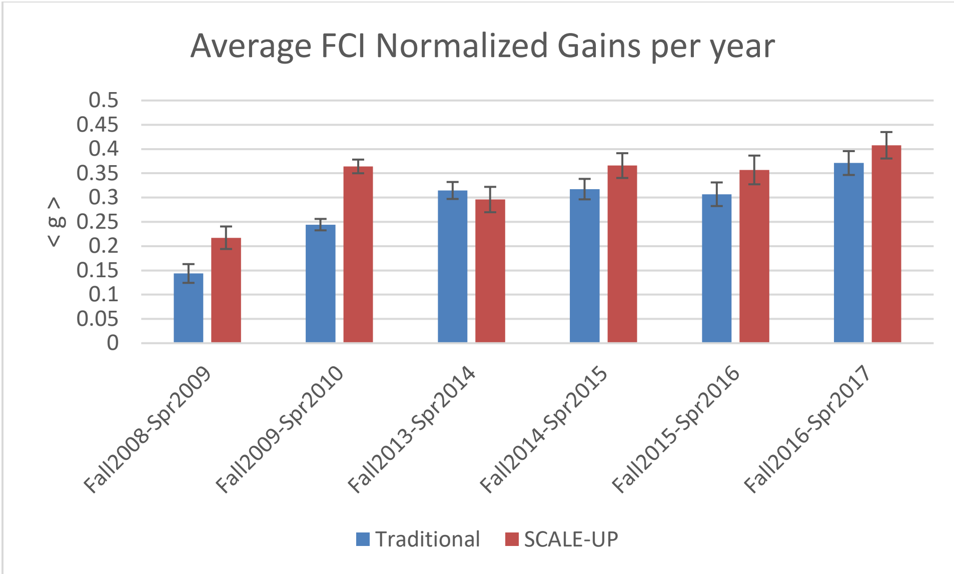

Figure 2.4.3 1 FCI normalized gains of Traditional and SCALE-UP classrooms between Fall2008 and Spring 2017.Standard error of means are shown for each year.

Figure 2.4.3.1 shows FCI normalized gains of Traditional and SCALE-UP classrooms for each year since Fall 2008. Data between Fall 2008 and Spring 2010 was collected and analyzed by previous graduate student, Brianna Upton [30]. She found that the normalized gains of SCALE-UP courses have significantly bigger normalized gains than Traditional courses between Fall 2008 and Spring 2010. But both classes average was under the national average normalized gains of interactive courses.

Table 2.4.3 2 Simple effect analysis. The table shows yearly normalized gains of Traditional and SCALE-UP courses are not significantly different (p > .05) between Fall 2013 and Spring 2017. STD: standard deviation, SEM: standard error of mean, df: degrees of freedom, Sig.: p-value.

		Mean	N	STD	SEM	t	df	Sig.
Fall2013-Spr2014	Traditional SCALE-UP	0.3146 0.2960	191 39	0.2416 0.1632	0.0175 0.0261	0.594	77	p > .05
Fall2014-Spr2015	Traditional SCALE-UP	0.3174 0.3659	164 87	0.2702 0.2382	0.0211 0.0255	1.408	249	p > .05
Fall2015-Spr2016	Traditional SCALE-UP	0.3068 0.3569	119 104	0.2654 0.3016	0.0243 0.0296	1.319	221	p > .05
Fall2016-Spr2017	Traditional SCALE-UP	0.3711 0.4078	154 70	0.3047 0.2280	0.0246 0.0273	-0.999	175	p > .05

Table 2.4.3 2 shows simple effect analysis of the normalized gains between Fall 2013 and Spring 2017. The analysis reveals that each year there is no significant difference in normalized gains of Traditional and SCALE-UP courses between Fall 2013 and Spring 2017. Cummings *et al.* found that just converting classrooms into studio mode does not improve student learning [31]. When studio classrooms are combined with research-based student activities, this increases students learning. Findings of this study support this claim. In the first year of the studio, even though SCALE-UP had higher conceptual learning gains than Traditional classrooms, it is still in the average of national traditional normalized gain averages [27]. In the following years of studio classrooms learning gains increased to the national range of interactive classrooms [27]. The first year of implementation of SCALE-UP in GSU was a learning process for instructors and implementers, SCALE-UP classrooms was like a classroom with computers. In the following years, new instructors were hired who had experience with SCALE-UP classrooms. Also, there have been meetings to discuss ways to improve research-based instructional strategies in SCALE-UP classrooms. Over the years, students' learning increased after instructors included more active learning strategies in their classes. Since with the instructor survey, it has been shown that instructors also applied interactive teaching techniques into Traditional classes, their learning gains also increased.

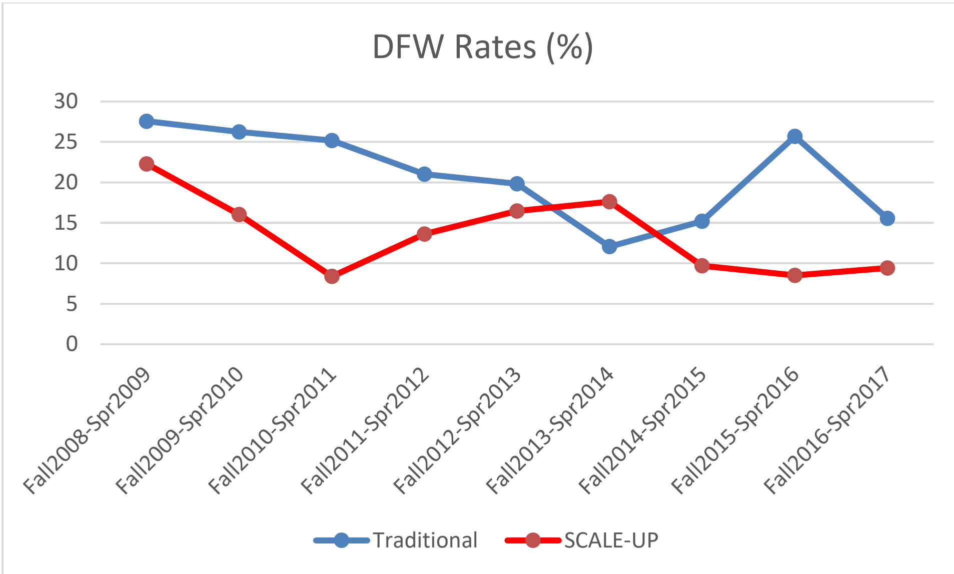

Figure 2.4.3 2 DFW rates of Traditional and SCALE-UP classrooms between Fall2008 and Spring 2017.

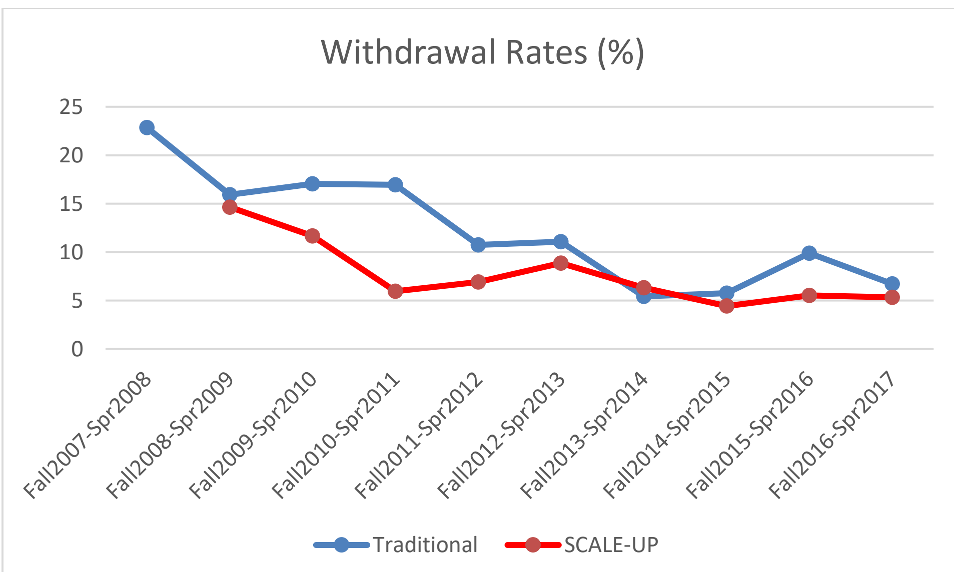

Figure 2.4.3 3 Withdrawal rates of Traditional and SCALE-UP classrooms between Fall 2008 and Spring 2017.

Retention rates of SCALE-UP and Traditional courses were calculated by finding DFW and withdrawal rates of these courses and are shown in Figures 2.4.2.2 and 2.4.2.3. Before the implementation of SCALE-UP, failure rates of algebra-based introductory physics at GSU were over 30%. With the introduction of SCALE-UP, failure rates dropped and after the third year were under 10%. With some fluctuations over the last years, failure rates have been between 10% and 20%. After the implementation, failure rates of Traditional classrooms are also decreased. Compared to SCALE-UP, they decreased slowly. But, after seven years of implementation, Traditional and SCALE-UP classrooms become similar.

A meta-analysis of 225 studies with 29,300 students showed that failure rates of interactive classrooms are lower than Traditional classrooms, 21.8%, and 33.8%, respectively [36]. Previous findings in SCALE-UP classrooms also support this argument, greater the amount of interactive engagement, higher student learning, and fewer failure rates [28, 8]. SCALE-UP classrooms have fewer failure rates than traditional classrooms [28]. The findings of this study support these previous findings. In the first year of the implementation, SCALE-UP had fewer failure rates than Traditional classrooms. Within years, failure rates of Traditional classrooms are decreased as parallel to the increasing interactive engagement in the Traditional classrooms.

2.5 Conclusions

With the SCALE-UP implementation, conceptual learning of the students, retention rates, and learning attitudes improved. In the long term, having the SCALE-UP implementation contributed to a dynamic change in the physics department and influenced instructors to introduce interactive teaching techniques. As a result of having interactive teaching techniques in the Traditional courses, student learning and retention rates of the Traditional courses also improved. However, the learning attitudes of the students in the Traditional courses was not improved compared to SCALE-UP. Learning attitudes of students in Conceptual Understanding and Problem-Solving categories improved with SCALE-UP instruction. I suggest that the interactive lecture/lab nature of SCALE-UP might help students to see the conceptual understanding focus of labs and the problem-solving nature of lecture parts as a more coherent picture like experts view. Also, previous research claims lower student to instructor ratio is helpful to improve learning attitudes [26]. Even though SCALE-UP classrooms are large enrollment classes, students have more opportunities to interact with instructors and might help to improve learning attitudes.

However, this study only measures the persistence of students through courses, it doesn't measure how the impacts of these courses affect students' persistence through their majors. I suggest as a future work, there should be longitudinal study to investigate long term effects of these courses on persistence of students on their major.

2.6 Acknowledgements

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3 HOW MUCH CAN BE ACCOMPLISHED BY CHANGING ONLY LABORATORY PORTION OF THE INTRODUCTORY PHYSICS COURSES

3.1 Introduction/Background

Laboratories have been an important place in physics instruction that support lectures and where students can learn how to do science [1,2]. Traditional cookbook-like laboratories have been criticized for being too costly and having little impact on students' learning [1, 3, 4]. In these traditional labs, most of the time, students get lost while following the procedures; and they barely concentrate on understanding the basics of the concepts [1, 3, 4]. To increase students' learning, recent research suggests that students should be more active participants [5, 6, 7]. Investigative Science Learning Environment (ISLE) [8], Physics by Inquiry [9], Socratic Dialog Including laboratories [10], Workshop Physics [11], and Real-Time Physics [12] are aimed to make students' more active participants by asking students to design or discover some parts of the experiments. It has been claimed that if students learn something by themselves then they learn more like in inquiry-based labs. Tutorials like Tutorials in Introductory Physics [13], Open Source Tutorials [14], Cooperative Problem Solving (CPS) [15] have been shown to increase students' learning by making them more active. In this study, traditional verification-based experiments are replaced with inquiry-based labs and tutorials to make students more active in laboratories and help them to learn concepts themselves. In this study, the effects of these redesigned labs on conceptual learning, students' expert-like attitudes, and success rates are measured and compared with the traditional method.

Inquiry-based labs are not common in undergraduate education as much as K-12 education due to time limitations of the labs, an excessive amount of the content aimed to teach, or lack of time and effort of people to devote to design/implement these changes. However, there are still some research-based materials reported as inquiry-based labs and shown to be successful at increasing conceptual understanding such as Physics by Inquiry [9], Workshop Physics [11], Real-Time Physics [12], ISLE labs [8]. Other than inquiry-based labs, tutorials also are reported to improve students' conceptual learning [16, 17, 18]. These tutorials are developed to emphasize conceptual learning and qualitative reasoning. Previous implementations of tutorials also report that this renovation also is helpful for learning assistants to see teaching as a career. This may help to increase the number of high school physics teachers who have a physics degree. This is especially important because it has been reported that two of three high school teachers do not have a physics degree or minor in physics in the US [19]. This situation is likely to be a contribution to the current lower science background at high schools in the US [20]. Previous implementations of tutorials demonstrate that having undergraduate learning assistants to guide tutorials may influence them to think of teaching as a career, and this may help to increase the quality of STEM high school teachers and the knowledge of science majors in the future.

In this study, both inquiry-based labs and tutorials are used together to replace traditional labs. This implementation aimed to improve conceptual learning and students' success. The effect of this redesigned labs on conceptual understanding, students' expert-like views about physics, and success rates were measured and compared with traditional labs.

Data in this paper was collected from the first semester of the two-semester sequence of calculus-based introductory physics. Course included mechanic topics such as kinematics, Newton's laws, momentum, energy, oscillations, rotations, some thermodynamics. It did not include waves.

3.2 Settings/Implementation

Calculus-based introductory physics courses were compulsory for computer science, chemistry, and physics majors and were a science elective option for biology, neuroscience, and non-science majors. The student population of the first sequence of the calculus-based physics course was roughly 43% computer science and 23% chemistry with the remaining being physics, math, and non-science majors. The student body in calculus-based physics at GSU was more diverse compared to national averages, and it consisted of 30% African-American, 35% Asian, 27% Caucasian, 8% others. Calculus-based physics consisted of three hours of lecture and a separate three-hour laboratory per week with a single grade (75% of the grade from lecture and 25% of the grade from the lab portion). Laboratory portion of the calculus-based physics courses was converted to one-hour tutorials with undergraduate learning assistants (LAs) and two-hour inquiry-based labs beginning in Fall 2013. Traditional labs were not taught in calculus-based physics courses after the implementation. In this study, one-year of data before implementation and three-years of data after the implementation were compared. In this paper, before and after the renovation will be called Traditional Labs and Redesigned Labs, respectively.

In Traditional Labs, teaching assistants (TAs) were responsible for the labs during the entire three-hour. In the first fifteen minutes, students took short pre-quiz, which consisted of four questions about both the previous week's experiment and that day's experiment. After the quiz, TAs gave a short lecture about the experiment and equipment. Then, students did the experiments as a group. The TAs' job was to go around tables and check students' progress and help them when needed. Students had lab notebooks to note their data, analyze them, and answer questions about the experiments. Students mostly completed their work outside the lab hour and turned in their notebook one week later. There was no additional homework for Traditional Labs.

In the first hour of the Redesigned Labs, Tutorials in Introductory Physics [13] were led by LAs based on the model developed by the University of Colorado [17]. In the remaining two hours, inquiry-based experiments were guided by TAs. In the renovation, tutorial activities and experiments were aligned with the lectures of the course. The primary goal of this implementation was to improve physics instruction at GSU. The secondary and longitudinal goal of the study was to increase the number of well-qualified physics teachers. LAs were recruited from the students who took the course and showed an excellent performance in the class and an interest in teaching. LAs were mostly science majors. They were required to take a pedagogy course where they read education journals, learned teaching practices, and were trained in both pedagogy and content specifically. They also practiced the material with other LAs before they taught the material. They earned a modest stipend. There was no quiz for these labs. Students needed to complete tutorial homework to be handed in at the next lab meeting.

3.2.1 Characterizations of lab portions

Since traditional labs were converted into inquiry-based labs, in this study the level of inquiry of both traditional and inquiry-based labs were characterized. A rubric was built to characterize and compare the level of inquiry in Traditional and Redesigned Labs by utilizing existing work [21]. This existing work divided labs into six parts; Problem/Question, Theory/Background, Procedures/Design, Results analysis, Results communication, and Conclusion, as shown in Table 3.2.1.1. The level of inquiry of the experiments is determined by looking at which of these parts of the experiments were given in the lab manuals and which parts were left to students to determine themselves. For example, in Level 1 or Guided inquiry level, manuals provide information for the parts Problem/Question, Theory/Background, and

Procedures/Design but leave the Results analysis, Results communication and Conclusion parts for students to determine themselves.

Table 3.2.1 1 Rubric developed by Buck et al. [21] to characterize the level of inquiry of the labs (Terminology is changed). MP: Manual provides, SD: Student determine.

Characteristic	**Level 0: Confirmation**	**Level ½: Structured Inquiry**	**Level 1: Guided Inquiry**	**Level 2: Open Inquiry**	**Level 3: Authentic Inquiry**
Problem/Question	MP	MP	MP	MP	SD
Theory/Background	MP	MP	MP	MP	SD
Procedures/Design	MP	MP	MP	SD	SD
Results analysis	MP	MP	SD	SD	SD
Results communication	MP	SD	SD	SD	SD
Conclusion	MP	SD	SD	SD	SD

By utilizing the existing work's framework [21], questions were developed to determine which of these elements were provided in the manuals and which were left for students to figure out themselves. In this rubric, Results communication and Conclusion parts were combined, because, in the previous work, the difference between them did not affect the level of inquiry. The developed rubric with questions is attached in Appendix A.

Table 3.2.1 2 Characterization of the level of inquiry of the Traditional and Redesigned Labs at GSU (MP: Manual provides, SD: Student determine).

	Traditional Labs	**Redesigned Labs**
Problem/Question	MP	MP
Theory/Background	MP	SD
Procedures/Design	MP	Mostly MP

Results Analysis	MP	SD
Results communication and Conclusion	SD	SD

Characterization of the level of the inquiry of the Traditional and Redesigned Labs is shown in Table 3.2.1.2. In the Traditional Labs, most of the instructions were provided in the manual. For example, these were some instructions from the Procedures section: "*Set the track up so that the 0 cm mark on the scale is even with the edge of the table. Plug in the air supply. Connect the hose to the air supply and to the air track. Turn on the air*." It can be seen that all the instruction students needed to do the experiments and take the data was provided in the Procedures section of the Traditional Labs and Procedures section is characterized as manual provided (MP). In traditional experiments, as shown in Table 3.2.1.2, only Results communication and Conclusion parts were determined to be student determined (SD). These parts were given with questions like "*How would your graph look if the experiment involved completely elastic rather than inelastic collisions*?" By answering those, students discovered the interpretation of the results by themselves. So, Traditional Labs were characterized as a structured level of inquiry.

In the experiments of the Redesigned labs, the Problem section was always given. They did not have a Theory section. Instead, they had prediction questions such as "*Identify the forces on the cart when the fan is running. Then draw the free body diagram for the cart…Draw your prediction for the velocity vs. time graph for case*". These prediction questions helped students' express their own ideas and discover the theory behind the experiment themselves. So, this part was given by inquiry. Procedures/Design part was provided in most of the experiments in Redesigned labs. Sometimes, some part of the Procedures section was given by inquiry like designing either one or more parts of the experiment. For example, "*Now use Newton's Second Law and Hooke's Law to come up with an experiment that will allow you to determine the unknown spring constant from quantities you can measure*" asked student to design an experiment. Results analysis and Results communication/Conclusion parts were given by inquiry. Students discovered these parts via questions. These questions helped students to reconcile their ideas with the Predictions/Questions part. Questions in the Prediction part and reconcile questions in the Results communication part encouraged students to discuss with their group members and understand concepts better. This method was proven to be effective in the literature [5, 22].

To summarize, Redesigned Labs were very close to Guided Inquiry Level since Results analysis, Result communication, and Conclusion parts were given by inquiry and not provided with instructions in the manual. However, Redesigned Labs did not perfectly fit into the Guided Inquiry level because they did not have a theory section. There are similar inquiry-based materials in the literature that include a Theory section given by inquiry like ISLE [8], Real-Time Physics [12], Workshop Physics [11]. The rubric created by Buck *et al.* did not include a category for the Theory section given by inquiry when the Procedures section was provided in the manual [21].

3.2.2 Characterization of Lecture Parts

There was no reform implemented in the lecture part of the course. Traditional labs and Redesigned labs had similar lecture parts. A survey was built for instructors to characterize the lecture part of the courses and determine the traditional and interactive components of the courses. To determine whether lecture parts of the courses were traditional or interactive, a modified version of the survey created by Henderson *et al.* was used [31]. The survey aimed to characterize research-based instructional strategies that were used in the lecture part of the courses. This survey was given to instructors who taught the class at the time of the data was collected. Questions in the survey were like '*In your Physics 2211 course, how frequently do you use whole-class voting as an instructional strategy'*. Instructors could answer this question with "never, once or twice, several times, weekly, for nearly every class, multiple times every class." With this survey, the percentage of instructors who use certain interactive teaching methods was determined.

According to survey results, lectures in calculus-based introductory physics at GSU were not entirely traditional. Instructors reported that almost half of them spend some time with traditional lecturing in every class. All of them reported that they solved both quantitative and qualitative questions in each class. Eighty percent of the instructors reported that in every class they required students to solve conceptual problems and half of them reported that they asked students to solve a quantitative problem in each class. Forty percent of them reported that they at least one in each week allowed students to discuss ideas in small groups in their classrooms. Sixteen percent of them used voting as an instructional strategy in every class time. Twenty five percent of them required students to work in groups each week and asked them to share their results with the rest of the class. From these results, it was seen that the lecture parts of the physics classrooms of GSU were not taught as a traditional format. Lecturers adopted several research-based instructional techniques in their classrooms.

3.3 Data Collection/Methods

Force Concept Inventory (FCI) [23] was used to measure students' conceptual understanding. FCI, developed by Hestenes *et al.*, is one of the most commonly used instruments to measure conceptual learning in physics. The Colorado Learning Attitudes about Science Survey

(CLASS) [24] instrument was given to measure students' attitudes and beliefs about science and learning science. CLASS was developed and validated by Adams *et al.* at the University of Colorado. CLASS consists of 42 statements that students respond to them either agree or disagree on a five-point Likert-scale. An individual favorable score for a student was calculated by comparing student's agreement with experts' responses. By averaging percentage agreement of all students, overall favorable score and eight categories of attitudinal shifts of a class or reform were calculated.

FCI and CLASS were given both in the beginning and at the end of the semester in lab meeting. After completing FCI, students were asked to submit their answers to the computer and were invited to participate in research. If they consented to participate in the research, they were asked to take an online survey about their lab experience and complete CLASS. Data was used in this study only from students who agreed to participate in the research. Also, only matched FCI and CLASS data was included after eliminating the entries that had missing pre or post FCI or CLASS.

3.4 Results/Discussions

Success rates of the courses were calculated by taking the percentage of the students who pass the course with C or better grades which was sufficient to proceed to the second course. Success rates of the course with traditional and redesigned labs were measured and found as 86.0% and 91.2%, respectively, as shown in Table 3.4.1. With redesigned labs, success rates of the course were increased. A meta-analysis of 225 studies with 29,300 students showed that average success rates of interactive classrooms were higher than traditional classrooms, 78.2%, and 66.2%, respectively [25]. Success rates of traditional labs and redesigned labs were more than average success rates of the national interactive classrooms. This probably arose from the presence of the interactive components of the lecture part of both laboratory types explained in the settings section. With Redesigned labs, these success rates even increased more. The reason for this increase was using tutorials and inquiry-based experiments. When students learn something conceptually, they were more likely to succeed in the course than others resulting in this increase in success rates.

Table 3.4 1 Success, DFW and Withdrawal rates of the Traditional and Redesigned Labs between Fall2013 and Spring2017.

	N	**Success (%)**	**DFW (%)**	**Withdrawal (%)**
Traditional Labs	357	85.4	14.1	8.9
Redesigned Labs	1464	89.4	10.6	4.7

Table 3.4 2 FCI pre and post scores, normalized gains of Traditional and Redesigned Labs, Independent t-test statistics, and Cohen's d calculations between Fall2013 and Spring2017.

	FCI Pre (%)	FCI Post (%)	$< g >$
Traditional Labs (N = 226)	36 (1)	55 (2)	0.31 (0.01)
Redesigned Labs (N = 664)	37 (1)	62 (1)	0.41 (0.01)
t stat, *p* value (One tail)	t (888) = -0.22 p = 0.415	t (888) = -4.14 $p < 0.001$	t (391) = -4.38 $p < 0.001$
Cohen's d (C.I)	0.017	0.313	0.337

Conceptual learning of classrooms with both laboratory types were measured with FCI; results and statistics are shown in Table 3.42. FCI pre scores of the Traditional and Redesigned labs were 36% and 37%, respectively. An Independent t-test was conducted to test the difference between FCI pre both traditional and redesigned labs. There was no significant difference between

FCI pre scores of both labs means that students come with similar conceptual knowledge to both laboratory types. FCI normalized gains of the traditional and redesigned labs were 0.30 and 0.40, respectively. Independent t-test showed that there is a significant difference between normalized gains of traditional and redesigned labs. This significant difference proves that redesigned labs helped to increase students' conceptual understanding more than traditional labs. Cohen's d and p-value calculations also support t-test results can be seen in Table 3.4.2. The previous implementation of tutorials also reported that tutorials are helpful to increase conceptual learning [16, 17]. This study supports the success of tutorials. Inquiry-based labs may also contribute to this improvement in conceptual learning.

Hake defines 0 – 0.30 as low for normalized gains, 0.30 – 0.60 as medium, and 0.60 – 1 as high. He found that gains of traditional classrooms were generally in low range. On the contrary, gains of the interactive classrooms were in the medium range. With Redesigned labs, the average normalized gain reached to medium range. Also, with Redesigned labs, the FCI post score average reached over 60%, which is accepted as a threshold for learning Newtonian mechanics and kinematics [7].

Figure 3.41 shows CLASS favorable pre scores of both Traditional and Redesigned labs. An independent t-test was conducted to compare students' incoming attitudes and beliefs to Traditional labs and Redesigned labs. There was no significant difference in the CLASS pre scores of Traditional labs, and Redesigned labs in each category show that students come with similar attitudes and beliefs about physics to both of the courses.

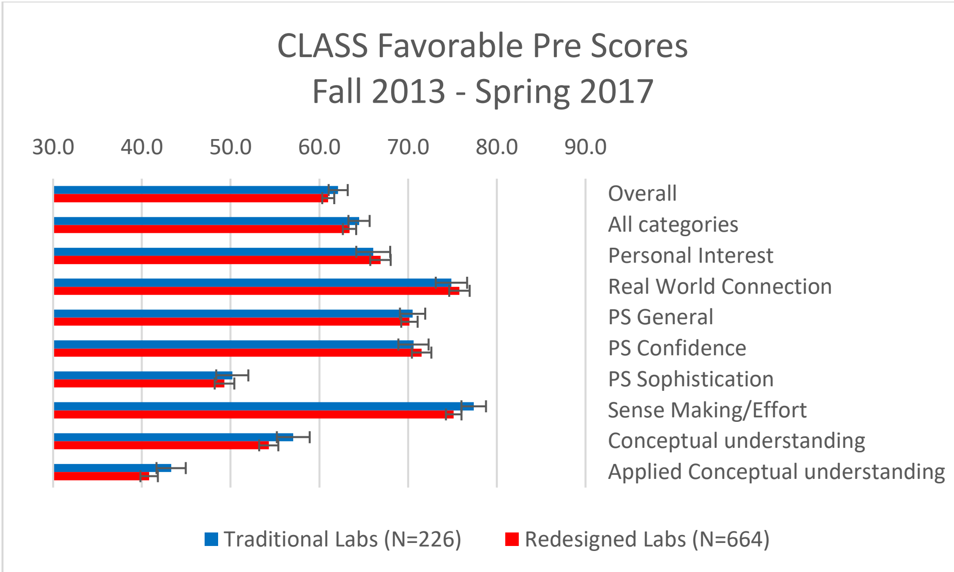

Figure 3.4 1 Average CLASS Favorable Pre Scores of Traditional and Redesigned Labs' Error bars indicate Standard Error of the Means.

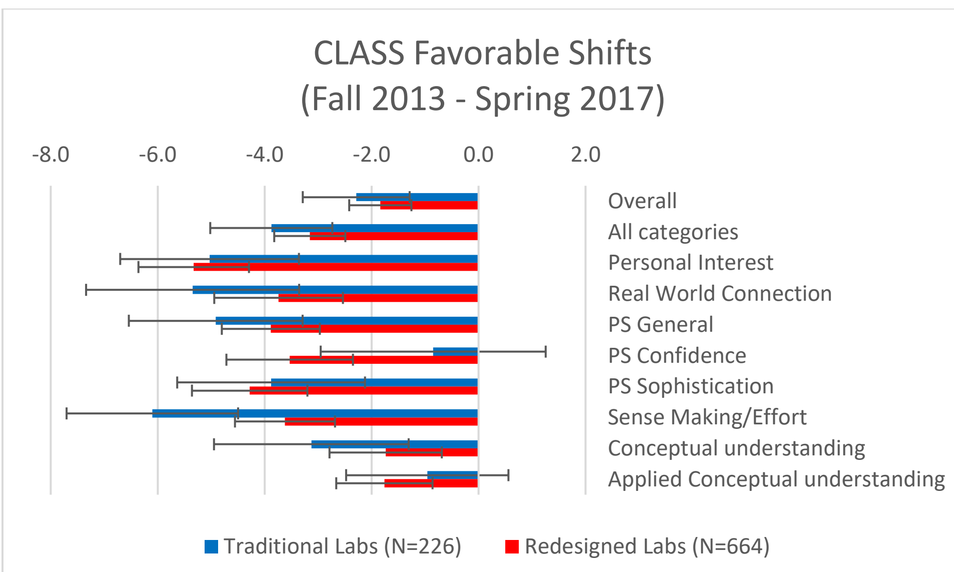

Figure 3.4 2 Average CLASS Favorable Shifts of Traditional and Redesigned Labs. Error bars indicate Standard Error of the Means.

Figure 3.4.2 shows CLASS favorable shifts of both Traditional and Redesigned labs. In both of them, shifts of students' attitudes and beliefs were negative in all categories. The dependent t-test was conducted to test the significance of shifts for each classroom in order to understand whether students' expert-like incoming beliefs and attitudes changed significantly over the course or not. Shifts in students' attitudes and beliefs about physics in overall and six sub-categories except for Problem-Solving Confidence and Applied Conceptual Understanding categories over the Traditional labs are significant ($p<.05$) and negative. For Redesigned labs, all the shifts were negative, and overall, Personal Interest and Problem-Solving categories were significant ($p<.05$). Since shifts in Real-World Connection, Sense-Making/Effort, and both conceptual understanding categories were not significant and smaller than twice the standard deviation of each category, they can be treated as neutral shifts [24].

Moreover, the shifts of Redesigned labs to Traditional labs were compared. Even though only Sense/Making Effort shift is significant ($p<0.05$), shifts in Redesigned labs in Real-World Connection, Sense/Making Effort, and Conceptual understanding categories are less negative than Traditional labs. Thus, Redesigned labs neither deteriorate nor help to improve students' expert-like beliefs and attitudes in the categories mentioned above. Negative shifts in expert-like attitudes are typical in the literature over the physics classrooms [24, 26, 27, 28, 29]. Having neutral shifts is often accepted as a success of the implementation because most of the classes even interactive courses result in negative shifts in learning attitudes [29]. The aim of the Redesigned labs was to address students' conceptual understanding with tutorials and scientific practices with inquiry labs. Having neutral shifts in conceptual understanding, Sense/Making Effort and Real-World Connection categories showed the success in redesigned labs. Also, negative shifts have been reported in the previous implementation of tutorials by different universities [16, 17, 18]. Measuring similar negative shifts in Redesigned labs, especially in Problem-Solving categories, may show that Redesigned labs do not help students to build expert-like beliefs in Problem-Solving categories. Redesigned labs had neutral shifts in some categories but not in problem-solving categories. This may show that addressing only conceptual understanding in the lab portion of the class might not help students to see the connection between concepts and problem solving as an expert-like.

3.5 Conclusions/Discussions

In this study, three-hour traditional labs were replaced with one-hour tutorials with LAs and two-hour inquiry-based labs. Lecture parts of the Traditional and Redesigned Labs were similar. The level of inquiry of the labs was characterized by modifying the previous work[7]. In Traditional labs, only Result communication and Conclusions parts were given by inquiry. Other parts were provided in the manual with traditional step-by-step types of instructions. Experiments of the Traditional labs perfectly fit in Level ½ Structural Inquiry.

On the other hand, experiments of the Redesigned labs were closer to Guided Inquiry, because Problem and Procedures section were provided in the manual. Moreover, Result analysis, Results communication, and Conclusion parts were given by inquiry. However, they were not perfectly fit into that Guided Inquiry level because Theory part of the Redesigned Labs was not provided in the manual. Instead, Redesigned labs had prediction questions that allowed students' ideas to come out and helped them to discover the theory of the experiments themselves. Other inquiry-based materials in the literature like Real-Time Physics, Workshop Physics, and ISLE also do not provide a theory section with step-by-step instructions. Their theory sections also include predictions questions to help students' to discover that part themselves. The rubric created by Buck *et al.* does not include a category if the theory section is given by inquiry when the Procedures section is provided in the manual.

In this study, the effects of both Traditional labs and Redesigned labs on success rates, conceptual understanding, and students' expert-like attitudes were measured and compared. Redesigned labs had higher success rates than Traditional labs. Also, Redesigned labs improved students' conceptual understanding more than Traditional labs. The previous implementations of tutorials and other inquiry-based experiments also showed success in increasing conceptual learning. In this study, it was shown that when tutorials and inquiry-based labs are used in the same time block, they also showed improvements in conceptual understanding and success rates. However, both Traditional and Redesigned labs had negative expert-like shifts that mean that they were not sufficient enough to improve students' attitudes. Even though Redesigned labs showed less negative shifts than Traditional labs in Sense-Making/Effort and Conceptual understanding categories, this may be seen as a small effect. These negative shifts with tutorials are common in the previous implementation of the tutorials. A more explanatory and qualitative study has been done to explain this and published by Ali ad Thoms [30].

Overall, it was found that replacing Traditional labs with tutorials and inquiry labs without changing lectures was effective in increasing the percentage of the students who pass the course and also increased their conceptual learning in introductory physics courses. However, it was found that changing the lab only was not sufficient to effect the students' expert-like learning attitudes. To affect both students' learning and their expert-like attitudes, more comprehensive implementation may be needed that includes both lab and lecture part of the course.

3.6 Acknowledgements

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4 INVESTIGATION OF UNDERGRADUATE PHYSICS MAJORS' IDENTITY DEVELOPMENT AND INTEGRATION

4.1 Introduction

The largest number of bachelor's degrees earned in science and engineering in 2014 belongs to India and China (1.9 and 1.7 million, respectively), followed by the United States (742,000), Russia (429,000), and Japan (316,000) [1]. Only one of seven degrees held in the United States belongs to natural sciences [1]. This rate is similar to proportions awarded natural science degrees in Canada, New Zealand, the Czech Republic, South Africa, Germany, and Armenia but less than the United Kingdom (21%) [1]. National Academies describes having low rates of STEM degrees as not being able to contribute to "global storm," and this endangers not only the "country's capacity to compete in a globalizing economy effectively" but also the prosperity of individual Americans [1, 2]. National Science Board alerted as a global crisis and reform STEM education [2].

However, nearly three of ten students who entered to study physical sciences are graduating with the same degree nationally [3]. This is one of the big reasons for low rates of STEM degrees in the United States. Retention is challenging to study subject quantitatively and qualitative both at the university level and national level because it is challenging to keep track of students and to reach out to student after they transferred to other universities or drop out from college. For these reasons, the aim of this research is to examine persistence decisions by characterizing the physics majors who stayed in physics.

The number of physics majors at GSU has risen rapidly in recent years. Figure 4.1.1 shows the growth of undergraduate physics numbers over the years. The number of undergraduate physics majors enrolled in GSU averaged 72 between Fall 2005 to Fall 2008 and increased rapidly after that. The number of physics majors between Fall 2014 and Fall 2019 averaged 190. The total number of physics majors in the last years was triple the number of enrolled physics majors in Fall 2005.

The national percentage of physics BS degrees received by underrepresented ethnic and racial minorities (URMs) is reported as about 10% between 2013 and 2015 [4]. The percentage of URMs receiving physics BS degrees at GSU is 33% in those years and was 60% last year, as shown in Figure 4.1.2. Georgia State is one of the top ten universities to award African American physics degrees [5]. Nationally, the percentage of physics BS degrees earned by women is 20% [6]. The percentage of BS degrees held by women at GSU has been similar to national numbers. Because of the diverse nature of the GSU physics program, it is a great place to study the underlying factors that leads students to stay in physics.

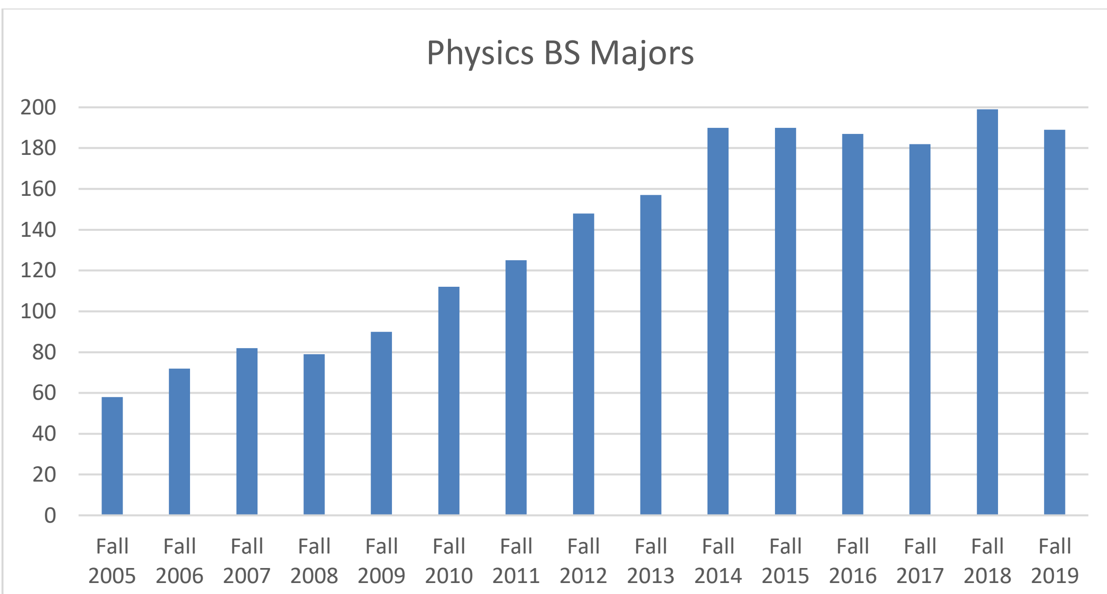

Figure 4.1 1 The total number of enrolled undergraduate physics majors each year since 2005.

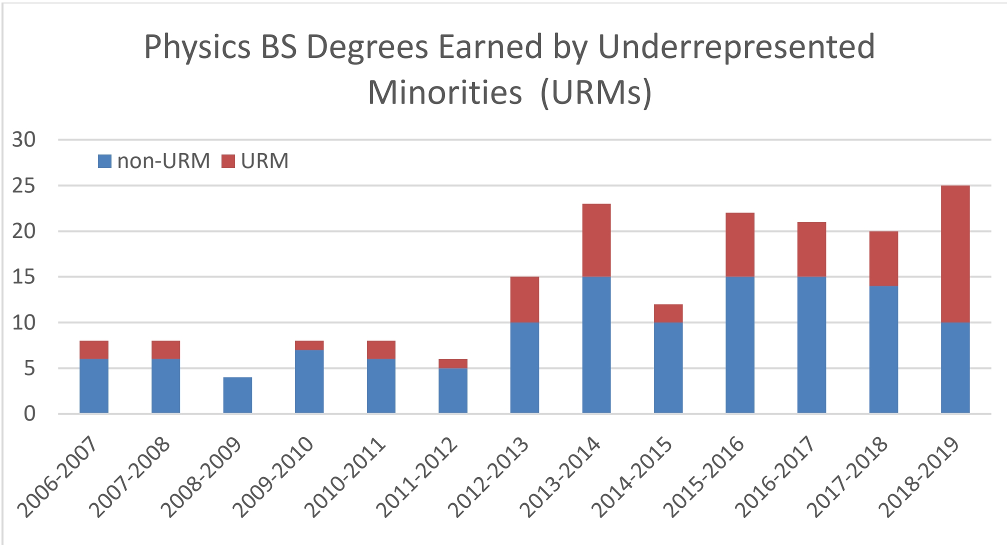

Figure 4.1 2 The number of degrees earned by URM and non-URM physics majors each year.

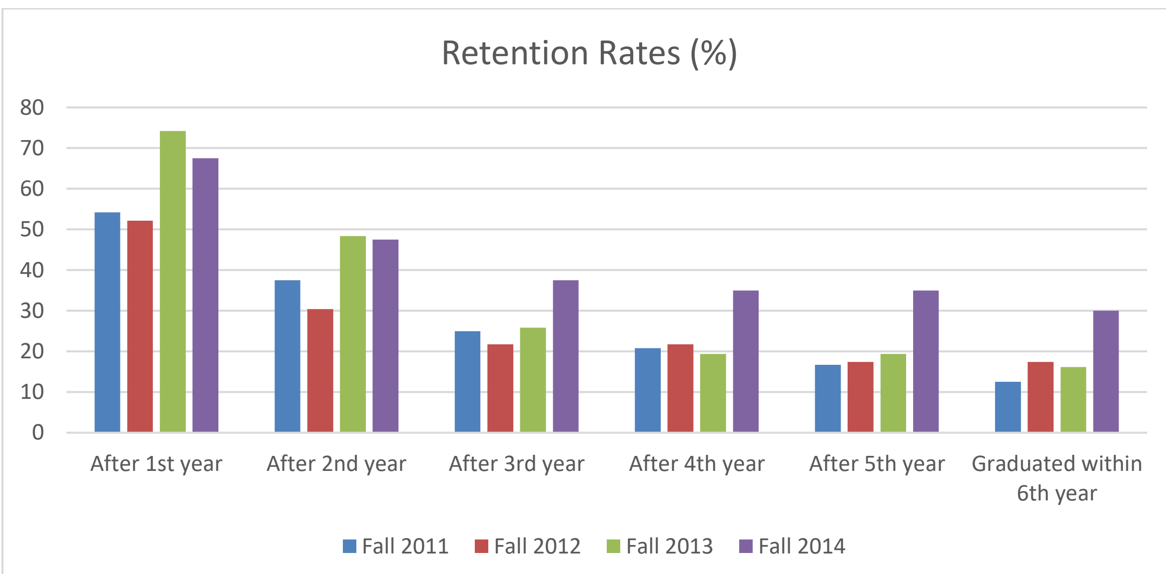

Figure 4.1 3 Retention rates of the students who start as majors in physics between Fall 2011 and Fall 2014.

Figure 4.1.3 shows the retention rates of physics majors. The numbers of physics majors who enrolled as freshmen are 24, 23, 31, and 40 in the years from Fall 2011 to Fall 2014. The graph shows the percentage of the students who remained as physics majors or graduated in each of the following years. This graph shows that most of the students leave physics in the first two years, and this confirms the literature. There is no information about why students left physics, or which major they switched into or maybe dropped. The focus of this project is to investigate the characteristics of students who stayed in physics rather than to learn why these students leave physics.

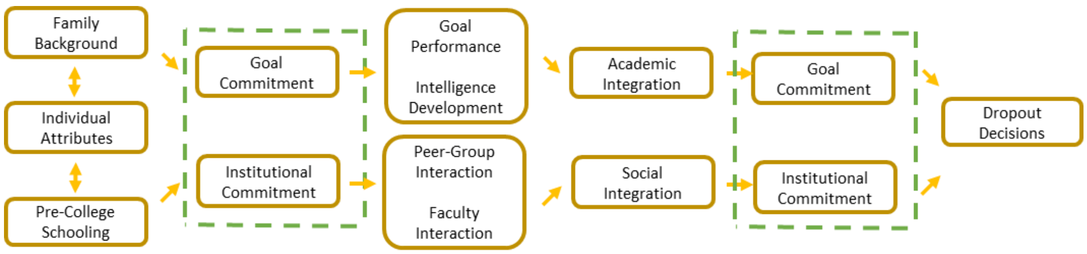

Figure 4.1 4 The conceptual schema of dropout decisions from college according to Tinto [7].

To be able to understand the reasoning lying under retention choices students make, several previous theories were explored and considered when I framed this study. Tinto's integration theory is one of the oldest theories that explain persistence at institutions regardless of major, as shown in Figure 4.1.4 [7]. Tinto claims that individuals' intentions and commitments when they enter institutions influence persistence in college. These refer to students' plans to major in STEM for our case, which affects persistence [8]. According to Tinto, students' intentions and commitments are both academic goal-oriented and institutional. These commitments influence intelligence developments and relations with the faculty and peers, which in result leads them to revisit their goal and institutional commitments. These two commitments will be influential when they make dropout decisions. Tinto's integration theory played a pivotal role in leading other theories but also criticized for implying that all students should be assimilated into white male culture [9].

While integration theory focuses on more relationships with faculty and students, Social Cognitive Career Theory (SCCT) relies more on students' career goals and actions that students are taking based on their goals [10]. As shown in Figure 4.1.5, SCCT claims that four major factors influence students' career choices: self-efficacy, outcome expectations, interest, and career goals. "Self-efficacy" is described as one's own beliefs about his/her capability to do something [10]. "Outcome expectations" is what students expect to gain as a result of a particular career choice, like deciding a major or doing internship [10]. According to SCCT, students' self-efficacy and outcome expectations influence their interest in a career like majoring physics and, in turn, leads them to set goals related to that career might be taking a physics class or doing research in a specific field [10].

Furthermore, setting these goals leads them to take actions and carry out their goals. After making these career-related actions depending on whether their performance, students' self-efficacy, and outcome expectation will be influenced, which will lead them to the next goals and actions. This is the cycle of how SCCT explains the students' career actions. Since staying in physics or leaving physics is also one of the career actions that take SCCT can explain how students make those choices.

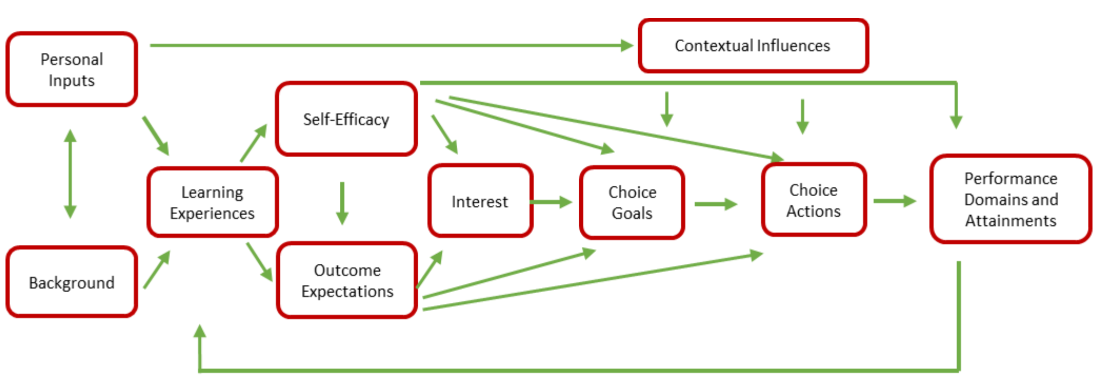

Figure 4.1 5 The framework of Social Cognitive Career Theory (SCCT)[10].

Science Identity Theory is the other theory that explains the factors that shape one's own identity in science and influences his/her career choices [11]. These factors are performance, competence, interest and recognition. "Recognition" means one's own beliefs about how other people recognize him/her as being good in that field. "Performance" refers to someone's self-beliefs about his/her ability to perform specific tasks in that field might be getting good grades or executing specific experiments [11]. "Competence" refers to one's self-beliefs about his/her knowledge and understanding [11]. In theory, even though performance and competence are distinct from each other, in real life, they are closely linked. That is why Hazari *et al.* combined those two concepts [12]. Also, Hazari *et al.* found that interest is also a fundamental part of one's identity and influences his/her career choice, which is what SCCT also suggests [12, 10].

This research combines these three frameworks (Tinto's integration theory, SCCT, and physics identity theory) and explores how the factors in these frameworks affect undergraduate physics majors' decisions to stay or leave the major [7, 10, 12]. There is a great deal of overlap between these three frameworks. For instance, performance, competence, and self-efficacy are closely related since they all related how well students feel performing in the coursework or the field general.

Other than these three frameworks, I also investigated research experiences since it is reported related to persistence [13, 14]. Participation of undergraduate students in research has given great importance in the last decades and supported by various institutions such as National Science Foundation (NSF) through Research Experiences for Undergraduates (REU) programs or Council on Undergraduate Research. Many of the reasons why undergraduate research experiences gained importance are related to reported impacts. Some of the published benefits of research experiences are listed below:

- persistence [13, 14]
- potential to improve students' abilities to think as a scientist [13, 15, 16, 17]
- abilities in science literacy [15, 16, 18]
- knowledge [19]
- enhanced career preparedness like clarification of career plans [13, 15, 16, 17, 20]
- intensified career preparation for research and science careers [13, 15, 16, 17, 20]
- interest in pursuing science careers increase skills [21, 22, 23]
- improvements in critical thinking, enhanced self-efficacy [13, 15, 16]
- increased sense of belonging to the learning community [15, 16]
- gaining interest in science [13, 15, 16, 17, 20]
- increase in recruitment of students of color into science [13, 15]
- its power as an instructional tool [24, 25], improved skills in lab and research skills [13, 15, 16, 17, 20]

Nevertheless, there is not much research to explore how research experiences are related to identity, integration, and retention. Hunter *et al.* compared how the outcomes of research are seen by faculty and students differently, and it has been found that students emphasized more on the personal outcomes of research while faculty focused on the process of socialization into science [26]. Faber and Benson studied how engineering students view their research experiences, and they found that students see themselves as a researcher because of their interest, competence and personal traits which are included in Hazari's identity theory [12, 27]. Examining undergraduate research experiences is not the primary goal of this study, however, since they are a vital part of undergraduate experiences and influence persistence and retention, it has been investigated as a part of this dissertation.

4.1.1 Research Questions

1. What are the characteristics of students who stayed in the physics program?
2. Which experiences or activities influenced students' physics identity, their career choices like plans after graduation, or decisions to stay in physics?
3. What are the differences or similarities of physics majors at a different stage of the program?

4.2 Research Design

4.2.1 Courses Descriptions and Design of Study

Since the goal of this study is to characterize the student population who stays in physics, our first motivation is to be able to recruit students equally from freshman to senior. Therefore, four courses are determined to be significant and have been taken by the majority of the students who are in the same stage of the program. For example, mostly sophomore physics majors enroll in a calculus-based introductory physics course, while juniors take advanced physics labs. Table 4.2.1.1 shows the names of courses and the level of students who take these courses.

Table 4.2.1 1 Course names in which students have been recruited into the study.

Students' program level	Freshman	Sophomore	Junior	Senior
Course Name	Gateway to Physics	Introductory Calculus-Based Physics Courses	Advanced Physics Laboratory	Research Project

Gateway to Physics course is a seminar-style course. Students are advised to take this course in their freshman year or their first year at the GSU if they are transfer students. In this course, students are introduced to the physics department, learn about career opportunities in physics. Also, the physics faculty gives presentations about their researches. At the end of the semester, students are required to explore and give a presentation about the fields of their interest.

Introductory calculus-based courses are the fundamental physics courses that physics majors take with other majors, usually in their sophomore year, after they have completed calculus requirements. Some physics majors do not take these intro physics courses, thanks to having AP credits.

After intro physics courses, students take upper-level physics courses like statistical physics, electromagnetism. Also, they are required to take the Advanced Physics Labs course. In this course, students learn practical skills like scientific ethics, literature skills, experimental design, data analysis, computer skills, data acquisition with computers, and the use of research equipment. Scientific thinking and communication skills are emphasized in this course. Also, research opportunities in the department are introduced with short presentations. After this course, students decide professors that they want to do research.

After taking Advanced Physics Lab, physics majors are required to complete the Research Project course where they need to do authentic research. In this course, one hour per week is spent on discussing the writing assignments, including research proposals and research reports, and other issues of research practice. Furthermore, six to eight hours per week is spent conducting authentic research within a research group which students choose based on their interest.

These four courses are chosen as key points to collect data where all students from each level of the program can be included. Also, these courses have flexible time in which researchers could able to go to class and to invite the students into to the project if it is needed.

4.2.2 Data Collection and Recruitment Information

This study is designed as qualitative research that investigates the factors that influence students' persistence decisions. The data collection has been done via interviews. Students have been invited to participate in a paid interview via email.

The interview is designed as semi-structured and aims to understand students' physics identity development, recognition, research and class experiences, their academic goals and preparations, and their recognition. After IRB approved the study, I have sent an invitation email to all physics majors to participate in our study. After students stated their interest in the study, an interview is scheduled based on their convenience. Interviews are structured as semi-structured. Interview protocol is attached in Appendix C. Interviews durations are approximately thirty to sixty minutes per person. The interviews are done in the researchers' office and audio recorded.

4.2.3 Student Population

Interviews have done in two rounds. Some questions are revised in the second round. Seven students have been interviewed in the first round, and thirteen students are interviewed for the second round. From both rounds, thirteen interviews are coded and analyzed. Seven interviews are not included in the analysis because those students' answers were short, and they did not answer some of the questions in the interview. Table 4.2.1.3 shows class standing, sex, race, and ethnicity information of the students whose interviews are coded and analyzed. This data is collected via university and students consented for the use of this demographic data for the study. At Georgia State, race and ethnicity are asked separately and are shown separately in the table.

Table 4.2.3 1 Class standings, gender, race and ethnicity information of students who are interviewed and included in the data.

Class Standing	Gender	Race	Ethnicity
Freshman 3 Sophomore: 2 Junior: 3 Senior: 5	Female: 5 Male: 8	Asian: 3 Black: 2 Multi-ethnic: 2 White: 5	Hispanic: 2

4.2.4 Methodology and Methods

The approach in our study is both ethnographic and phenomenographic, in which I focused on both qualitatively analyzing perspective of students' shared experiences and the different ways of people experiencing a particular phenomenon.

Phenomenology is different from phenomenography. Phenomenology aims to have a complete picture of how people experience certain phenomena. On the other hand, the goal of phenomenography is to understand the similarities and differences of how people experience certain phenomena and to be able to create categories within how the phenomenon is experienced. In our study, I aim to understand the differences and similarities of how physics identity is developed within students in various stages of the program and how this affects retention. That is why phenomenography suits perfectly to our goals.

4.2.5 Data Coding and Analysis

I have combined the analyses described by Kleiman and Creswell (2013) [28, 29].

1. I read each interview transcript individually to get a sense of whole interviews.
2. Transcripts are read second time more slowly and "developed a list of significant statements" described by Creswell (2013, p 193) to understand the foundations of a phenomenon [29]. When developing this list, I "treat each statement as having equal worth and works to develop a list of non-repetitive non-overlapping statements" [29].

3. After the development of the list of statements, we took significant statements. I then grouped them into larger units of information, called "meaning units" or themes" (Creswell 2013,p. 193), to be able to have a complete conceptual picture of how the phenomenon is experienced [29].
4. The next step is to form a large unit of information. Creswell suggested that researchers should "Write a description of "what" the participants in the study experienced within the phenomenon" [29]. According to Creswell, this is known as the "textural description" of the participants' experiences, and the written descriptions of what happened to the research participants must include verbatim examples [29]. At this stage of the phenomenological method of analysis, Creswell (2013, p. 194) suggested that researchers should write a "description of "how" the experience happened" [29]. I have focused on understanding differences and similarities of how the phenomenon is experienced, in our case, how physics identity is developed in different stages of the undergraduate program rather than having a complete picture. To reach this goal, the responses from the responses of students from different levels of the program or students with different experiences are compared.
5. I have revisited the raw data descriptions to justify our interpretations of textural descriptions.

4.3 Results & Discussion

4.3.1 Decisions to be physics major

To investigate students' motivations, physics identity, and career goals before they start major in physics as the first step of the retention, they are asked: "how did you decide to be a physics major." Data is collected during the second round of interviews. This question is not asked for the first round.

Table 4.3.1 1 The number of responses of why students decided to major in physics.

Interest	7
Influence from higher roles	3
Influence from science media	3
Engineering goals	3
Science recognition	1
Math performance	1
Physics performance	1

Table 4.3.1.1 shows the number of responses to why students decided to major in physics. More than half of the interviewees stated that they wanted to major in physics because of their interest in physics, astronomy or math. The other two common responses are the influence from higher roles like parents, teachers either in college or high school, and science media like science fiction or non-fiction movies or books, or science shows like Neil deGrasse Tyson's NOVA ScienceNow show. Influence from the higher roles and science media is related to interest because they stated that they gain interest by the influence of higher roles or science media. Interest has been shown as one of the factors that contribute to one's physics identity by Hazari *et al.* [12]. From the responses to this question, students state that that they started to feel like physics person or physics nerd because of the experiences of taking classes and gaining interest, and they decided to major in physics.

The other common reason for the students why they decided to be physics majors is their engineering goals. At Georgia State University, there is no engineering degree offered. Students who could not get into the engineering program usually prefer to major in physics with the plans to be able to transfer later into engineering programs. Moreover, students stated that mostly choose physics because they believe physics is closer to engineering programs than other STEM degrees, they can take some of the required courses in physics major before they transfer.

Other non-frequent reasons why students decided to major in physics are science recognition, math, and physics performance, meaning students' beliefs about being good at math and physics in high school. Believing in being good at math and science courses at high school and having increased self-efficacy because of their performance has been reported as being the most critical factor in deciding major in STEM [30, 31]. Feeling recognized as a science/physics person or believing that they have good performance in physics has also been reported as essential factors that contribute to one's physics identity along with interest [12]. Furthermore, by developing this pre-college physics identity, students decide to major in physics.

Overall, our interviews with physics majors about why they decided to major in physics is the first step in explaining retention, and it fits perfectly with SCCT and identity framework (see table 4.2.1) [12, 10]. In high school, students gain interest in physics Students' interest, their outcome expectations like transferring plans to engineering, their self-efficacy/competence beliefs influence them to take career action like, in this case, deciding to be a physics major. There is no significant difference by gender, class standing, or race/ethnicity.

4.3.2 Comparison of undergraduate physics majors' image of physicist and themselves

To understand physics majors' ideas about physicists, two questions below are asked:

1. What characterizes a physicist in your mind?
2. How do you think one becomes a physicist?

These two questions are coded and analyzed together.

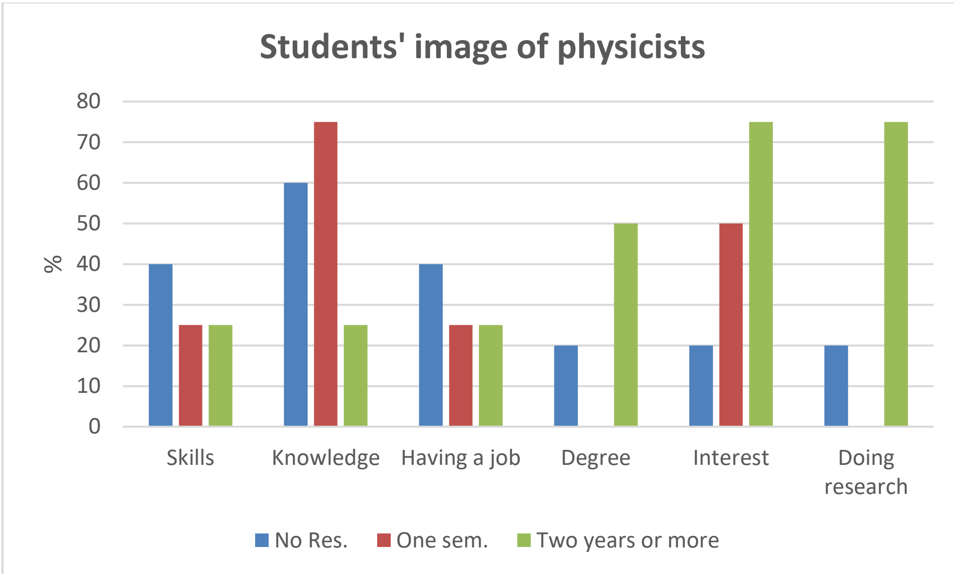

*Figure 4.3.2 1 The frequency of responses of students ideas of physicists (**No Res.:** Students with no research experience, **One sem.**: Students with one-semester research experience **Two years or more**: Students with two years or more research experience).*

Students have similar responses for the interview questions based on the level of research experiences they have. Thus, students' responses are categorized into three groups: students with no research experiences, students with one semester research experience and students with two years or more research experiences. Figure 4.3.2.1 shows the frequency of responses about their ideas of a physicist. Students who have done two years or more research reported that in order to be a physicist, one must have at least a bachelor's degree in physics and an interest in physics to do more. Also, they state that doing research is a significant component that makes people physicist. Students with one-semester research experience or no research experience reported that to be a physicist, one needs to have the knowledge and/or a job in physics. Also, they believe that one needs to have some skills in order to be a physicist, like to be able to communicate knowledge or ability to connect math and physics. The results show that students with more research experience have more experience-oriented ideas about physicist rather than knowledge focused ideas. This can be due to students with more research experiences might feel that they have enough knowledge and they are more focused on getting experience at this point of their career.

In order to understand students' physics identity, I asked them, "Do you consider yourself a physicist, physics student, or physics person?" Figure 4.3.2.2 shows the percentage of students who said they feel themselves as a physicist. All the students with no research experience stated that they do not feel themselves as a physicist yet. However, they stated they have some level of physics identity. They stated that they see themselves as a physics person, physics nerd, or physics student. Half of the students who have done research also does not feel themselves as a physicist even though they are about graduate. Students who stated they do not feel themselves as a physicist, they describe themselves as a physics student, physics person, physicist in training—furthermore, two students who defines himself/herself as an engineer. Interviewees also explained why they feel themselves as physicists or not.

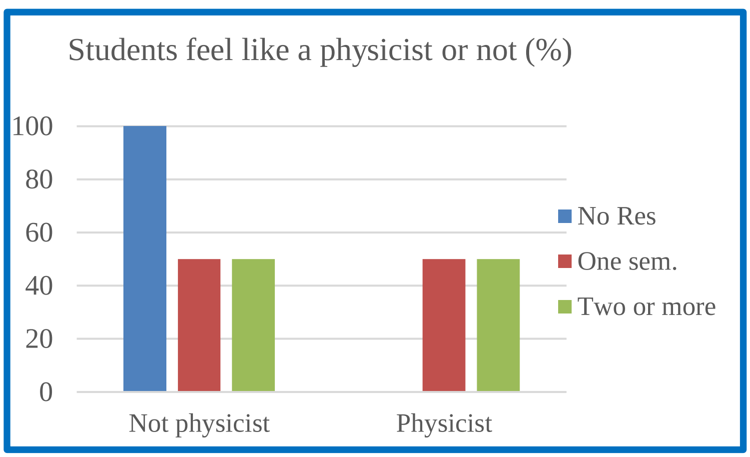

*Figure 4.3.2 2 The frequency of responses of students' feeling about themselves (**No Res.:** Students with no research experience, **One sem.**: Students with one-semester research experience **Two years or more**: Students with two years or more research experience).*

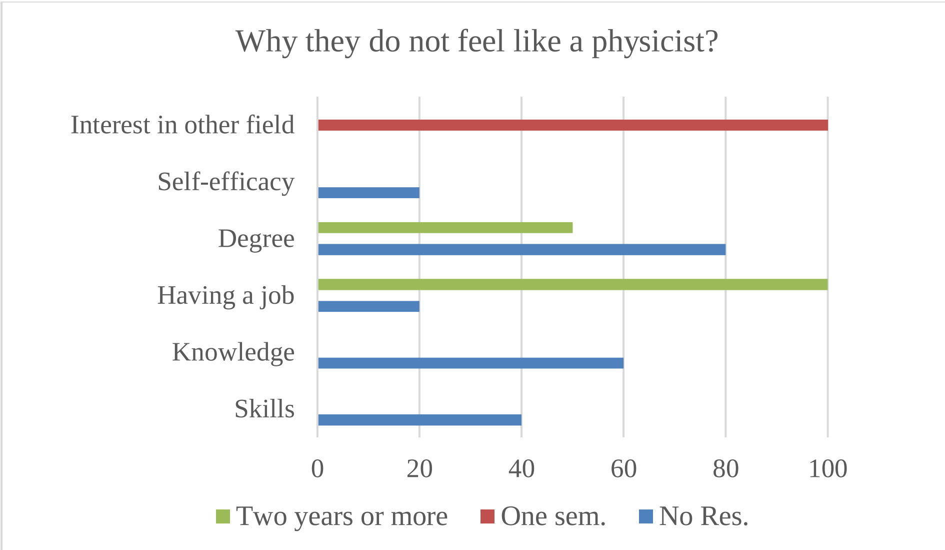

*Figure 4.3.2 3 The frequency of reasons for students why they do not feel themselves as a physicist (**No Res.:** Students with no research experience, **One sem.**: Students with one-semester research experience **Two years or more**: Students with two years or more research experience).*

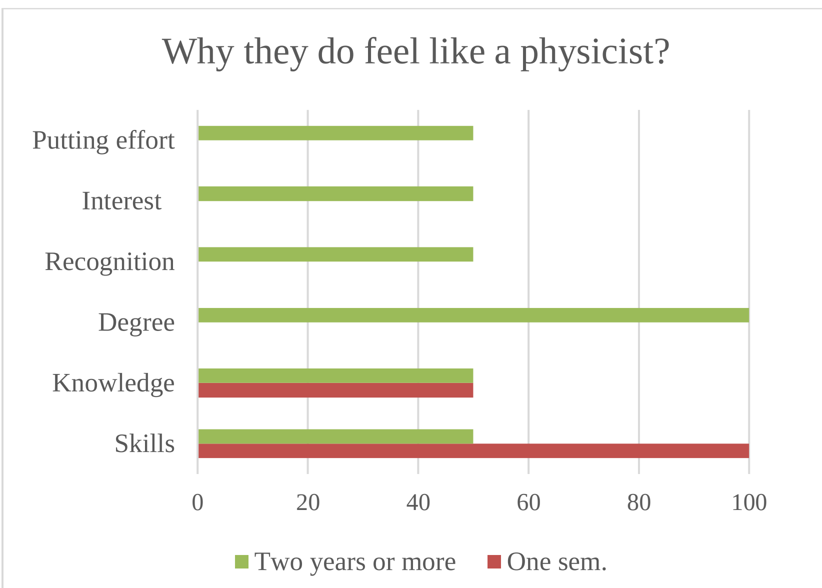

*Figure 4.3.2 4The frequency of reasons for students why they feel themselves as a physicist (**No Res.:** Students with no research experience, **One sem.**: Students with one-semester research experience **Two years or more**: Students with two years or more research experience).*

Figure 4.3.2 3 shows the reasons of students who do not feel themselves as a physicist. Students who have not done any research, they are in the earlier stage of the undergraduate program. And they stated that they do not feel themselves as a physicist because they feel that they do not have a degree, knowledge, or skills to call themselves as a physicist. On the other hand, students who have done two years or more research they do not mention about knowledge or skills. They stated that physicist should have a degree and a job, and since they do not have those yet, they do not want to call themselves as a physicist. Even though students with one-semester research experience are seniors and about to graduate, they stated that they have more interest in other fields like math or engineering than physics. That is why they do not feel like a physicist. These students stated that they have plans to pursue career goals related to other fields after graduation.

Only some of the students who have done research describe themselves as a physicist. Mostly they believe they have enough knowledge and skills to call themselves a physicist. Also, they believe they are about to have a degree as well to make them qualify to call themselves as a physicist. Moreover, some students believe having an interest in physics, or being a recognized member of a physicist and being put enough effort for physics degree is also makes them feel like a physicist.

Compared to students' image of a physicist, they do not mention doing research in their reasons of why they feel themselves as a physicist or not. Also, fewer students mention having an interest is a significant factor for calling themselves as a physicist when I compared to their ideas of physicists.

4.3.3 Undergraduate physics majors' integration to the department

4.3.3.1 Integration with faculty

In the first round of the interviews with five students, I have asked them three questions to understand the relations with the physics and astronomy faculty. These questions are below:

1. Do you think it is important to you personally to build relationships with faculty? Why?
2. Do you think it is important to your career success to build relationships with faculty? Why?
3. Which courses or academic activities do you think have strengthened your communication with the faculty members in the physics and astronomy community? Explain how?

I have not found any difference in responses for the first two questions, so they are analyzed together. Students mostly express that they feel that it is good to build relations with professors in order to get a recommendation letter for jobs or grad school or get help on a job search or networking. Also, only one student believes having good relationships with professors might be important if she needs to push her grades up.

Table 4.3.3.1 1 Reasons why students want to connect more with professors.
Total: 5

To get a recommendation letter	4
To find a job	2
To network	2
To push up grades	1

I also asked students to the third question to learn about which courses or activities are critical for them to build relations with faculty, and the answers might be the critical points in their career to make them choices about to stay in or leave the physics major. Three of the five students were seniors, and they have taken all the physics courses. Moreover, one of them was a freshman, and the other one was a junior. Two of the seniors reported that they found the advanced physics lab course as a place that helped them to build make connections. As a part of this course, professors come to class and give a presentation about their research. After this class, students decide in which field they want to do their research project, which is a requirement for graduations.

The other senior stated that she found every course useful to make relationships with faculty by attending office hours. She also stated that office hours could be an excellent chance for professors to know her.

Student H: I go to most of my professors' office hours to talk about physics. I suppose, and so I think it's good to build a relationship with your professor because it's like puts a face to a name.

One junior and freshman stated that they found the Gateway course helpful because of getting introduced to professors' research in that class. They stated that they got a chance to meet professors in their interested research field. They might do research later with them.

Student O: Gateway to physics classes is pretty cool because I get to get into looking into what all the different professors' researches are and actually be able to interact with them before I have a class with them. Like today, Dr. X, he is an astronomer here. His work was pretty cool, and I gotta talk to him and ask some questions and introduce myself.

Other than courses, only one senior mentioned that he found as useful to attend colloquiums to meet professors and get interaction with them.

From the first round of interviews, it is found that advanced physics labs and Gateway to physics courses are the ones students feel helps them both to make connections with faculty also to make choices about the research field they have an interest in. However, students did not talk about the depth of their relationship with their professors. In order to understand more about the depth of their relationship, I have decided to replace questions for the second round of the interviews with a more open-ended question. I asked them, “Would you please describe your relationship physics and astronomy faculty?”. Table 4.3.3.2 shows what is found from these questions.

Table 4.3.3.1 2 Physics majors’ integration with faculty.

No Res.	One Sem.	Two or more
These students report no integration with faculty.	This group reports very little integration even though they have taken upper-division courses and close to graduation.	They are about to complete their program, but they still report only a strong connection with their research advisor.

Seven students have been interviewed in the second round: four seniors, one freshman, and two juniors. It has been found that all of the students except one senior stated that they do not have many relations with the professors. Only one senior said that he feels he is connected to everyone in the department. Two of them reported they are planning to get connected to professors more because they think it will be helpful for them to find jobs or internship opportunities. Three of the seniors who have done two years or more research reported that even though they do not feel connected to professors, they feel they have strong relationships with their research advisors.

Student B: More so, with my research professor, I have more relations with him. I’ve known him for about two years, and we meet every week, and then anytime I need more help, I email and meet him at his office.

Two senior students stated he stated professors do not like teaching, and they feel condescending like professors do not value their knowledge that feeling causes him not to want to have relations with professors.

Student X: For me, personally, I have not had the best relationship with the faculty here. I felt like a lot of faculty here were very like hmm. W is great, and a few others, I forgot their names. They were good too. But others I am not gonna say their names, but others were kinda like they do not really care about teaching. I think if you are gonna be faculty at a university, you should be wanted to teach you should be wanting to teach to somebody. And if you are not gonna teach to somebody then why you are at a university, and these people did not feel like teaching. They felt like they get annoyed with you if you do not know something and just maybe not want to like. And sometimes maybe not even want to do research because just these people just up here and I am down here feels like.

Student B: Some professors are a little bit mean to a lot of students. They are... I do not wanna say, I mean, I would say. I do not know sometimes it can be a bit condescending sometimes, a couple of professors I also do not name their names. Sometimes they think that we do not know that much. If it kinda means a little bit. Cuz, obviously we're still learning, we're still students after all. You have so much experience, there is no need to be mean towards us. Sometimes it feels that sometimes it makes us feel bad. We're good as physics students. Sometimes some physics professors make us feel bad about being a physics student. I do not know. It is a bit bad sometimes.

From both the first round of interviews, advanced research lab, and Gateway to physics courses are the courses students mentioned they made relations with the physics faculty. They stated they had got a chance to meet professors who are working in their research field. From the second round of the interviews, it has been found that most of the students do not have many relations with the faculty. Only three students who have done two years or more research stated they only have strong connections with their advisors because of that they feel very connected to the department. When both rounds of the interviews are combined, research interests are the motivations for students to make relations with the faculty, and only students who have done two years or more research feel they feel integrated because of their relations with their research advisors. From these findings, it is clear how vital the Gateway to Physics course is to make these relations early on in students' careers that might help them to motivate them to stay in the physics program.

4.3.3.2 Integration with physics majors

Table 4.3.3.2 1 Physics majors' integration with other physics majors.

No Res.	**One Sem.**	**Two or more**
Not many relations Gateway to Physics course	Limited relations Upper-level courses	Limited relations Upper-level courses Research-related activities

Studies have shown that the integration of students with their peers from physics and supporting each other is crucial for their success and retention in the program [7]. Even though questions were different in the first and second round of interviews, students describe the depth of their relationship with other students. Because of that, both interviews are analyzed together for this question. Table 4.3.3.2 1 shows the findings of integration with physics majors. All students stated that they do not have close friendships with other physics majors. They do not speak outside of the class environment a lot. They reported that they only come together outside of class to do homework or group projects. They stated that upper physics courses are the place where they have homework. Because of the level of the difficulty of the homework, students form groups and work together with other physics majors. They reported that because of the homework portion of the upper-level courses, they made friends with other physics majors. Only one student mention having a close friend as a study buddy. He mentioned they met in freshman year, and they support each other through college. Students in the Gateway classes also stated that they do not have close friends in physics. However, they met other physics majors in the Gateway course, and they stated that they support each other and asked for advice on each other, like deciding which classes to take.

Student W: I do not speak to a lot of students very regularly. There are a few. So, I am in the society of physics students here, and it's not a very big club, or those are regularly coming. I know we talk about things for homework or maybe run across together.

4.4 Undergraduate physics majors' recognition

4.4.1 Physics majors' recognition by faculty

Feeling recognized by others, especially from other physicists, plays a critical role in developing one's physics identity [12]. Students' recognition by faculty is measured by asking them, "Do you feel you are recognized as a good physics student by your professors." Students described whether they feel recognized or not by their professors and explained why they feel that way.

Table 4.4.1 1 Recognition of physics majors.

Do not know whether they are recognized or not	4
Feel not recognized as a good student	2
Freshmen students	2
Feel recognized based on verbal verification	2
Feel recognized based on grades or efforts	3
Feel recognized by research advisors	5

Whether students feel recognized or not, is shown in Table 4.4.1.1. Only two of the students stated that they feel recognized by some of their professors. They stated that they had been told as being ranked at the top of the class. Moreover, this helped them to feel as recognized by their instructors.

Four of the students stated that they do not know whether they are recognized as good physics students by their professors or not because they reported that they do not have much communication with the professors. Three students also stated that they do not know certainly whether they are recognized or not by the physics and astronomy faculty as well because they reported that they had not got any verbal verification about this. However, these three stated that at some level, they feel recognized based on their grades, or based on efforts like attending office hours, arriving on time to classes. They stated that getting a good grade or making efforts to be successful in the class probably got their professors' attention. Because of that, they stated that getting good grades of putting enough effort helped them to feel recognized.

Student K: Just based on my grade, I think that they probably would [recognized me as good physics student]. I'm not disruptive in class. You know I arrive on time most of the time. So overall, I would get a passing grade as grading for a physics student.

Freshman students stated that they do not know much faculty here, and they have not got a chance to gain recognition yet. However, they stated that they felt recognized by their high school teachers based on their grades and their efforts in the class. They did not mention about any verbal verification from their teachers.

Students who are doing two years or more research stated that even though they are seniors and completed almost all physics courses, they stated that they do not have many relationships with the physics and astronomy faculty. However, they reported that they have great relationships with their research advisors. They meet regularly, and students stated that they feel themselves very close to their advisors.

Only two seniors stated that they feel recognized by the physics faculty because they are told that they ranked at the top of the class. These students mentioned they got verbal verification about their success in the class, and because of that, they stated that they felt recognized by their faculty.

4.4.2 Physics majors' recognition by their family

Being recognized as a good physics student by their family is investigated by asking in the interview with the question of "Do you feel you are recognized as a good physics student by your family." Most of the students (7/13) stated that they stated that they feel recognized as being good physics students by their parents. Five of the students stated that whether they have been seen as good physics students by their parents or not, their families support them. They mentioned that this support from parents helps them to continue to be a physics major. Two students stated that their parents do not support them in being a physicist. One of them already stated that he does not want to be a physics major and plan to get a master's degree in the engineering field. The other student mentioned that he became successful and won a scholarship and convince his parents that "being a physicist is something he can accomplish and make money out of it." None of the students stated that they feel recognized as bad physics students by their parents. However, four students stated that their parents do not understand what they are doing, and they stated that they do not relate themselves to their parents. Even though they feel their parents do not understand them, all of them stated that they had not been affected by this situation.

In conclusion, being recognized as a good physics student by their family, especially their parents, and supported by them either mentally or financially motivated them to continue as a physics major. When students feel their parents do not understand them, either their parents still support them to continue in physics or students feel they do not need their support to continue to be physics majors. Most students feel their self-motivation matter most to them to make choices for their career like continue as a physics major or what they are going to do after graduation. It has been stated in section 4.4.1 some students got influenced by their parents or their high school teachers when they decided to be a physics major. So, students' parents' ideas are influential in their early career choices. Nevertheless, I do not have any evidence that parents are affective on students' career choices during college.

4.4.3 Physics majors' recognition by other physics majors

Students' feeling of being recognized by their peers is measured by asking them, "Do you feel you are recognized as a good physics student by your classmates?" during the interview. Most of the students except one female student stated that they feel recognized by their classmates from other physics majors based on the evidence of their good grades (2), their effort in the classes (2), being asked for help on homework (8).

Only one female student stated that her male friends in the class do not value female's knowledge and competence. There is a quote from her interview below.

Student Y: There's like four girls in my statistical and thermal physics class. And I feel like there's like this automatic like thought like, in male physics students head like "oh they [female students] do not know what they're doing" or "if they [female students] get something wrong they're gonna cry.". And like they [male students] see like we are emotional people who do not know what we're doing and this is kind of annoying. They do not want us much put into effort *and like 'oh you do not have to do anything just sit okay. I think there's an assumption that we do not do as well as they do. I feel like if you're a girl, you're majoring in physics, and you do one thing wrong, or you say one like one dumb thing in class, they automatically just write you off. And say, "oh, she does not know what she's saying." But if they did the same thing they say "oh you know he just made a mistake, he knows what he's doing, and he just seems his head was messed up" when he asked a dumb question in class. I feel like you have to be on your game all the time. You have to know exactly what you're doing when you're like a girl and in a physics course, and it is annoying. And like I am just here to learn.*

She stated that since there are a few female students other than her in her classes and being seen as not competent enough as male students from her friends make her try to fight to be good continuously and live with the pressure of not making mistakes all the time.

Moreover, two students in the Gateway course stated that they had not got a chance to gain recognition yet. However, they feel like since they have a good relationship with other physics majors by helping each other, they felt like everyone thinks every one as good physics student.

4.4.4 Does feeling recognized is important?

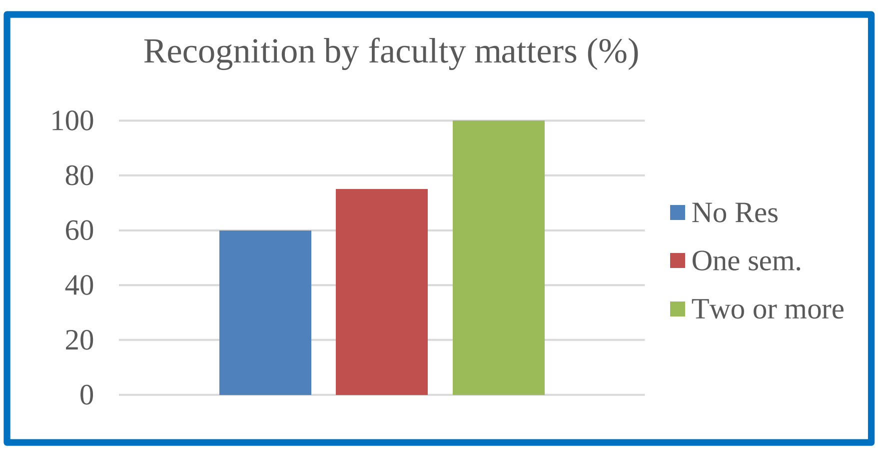

Figure 4.4.4 1 The frequency of responses who report recognition by faculty matters for them.

77% of the students believe that recognition from faculty does matter for them. However, only students who have done two years or more research have believed that they are recognized by their faculty. This graph shows how much students value being recognized by their professors. Since they also stated in section 4.4.1 that they look for verbal confirmations by professors in order to feel recognized and make sure about their performance, professors need to improve their interaction with students and appreciate more students' achievement in the course.

4.5 Undergraduate physics majors' research experiences

Research experiences are the most influential milestone for undergraduate students. Students' responses in this study are grouped based on the level of research experiences they have. Students with more research experiences have more experiences. They are more connected to the department due to their interaction within the research group. They are more confident about their performance and career choices. They also have a more comprehensive idea about what researchers do.

Students with only one-semester research experiences with the compulsory Research Project course stated that they just got used to equipment and tools. Even though they were not comfortable doing research on their own, they said they realized doing research is not a hard thing to do, and they might consider as a career choice after graduation.

Student I (one sem.): "No, because it is still like new… I was like trying to get used to tools and all that. I guess I mean that would be changed when I would continue to do in summer when I connect to more. Right now, it is like intro level, introduction to, and stuff."

Table 4.5 1 Research experiences of undergraduate physics majors.

One Sem.	Two or more
• Learned some programming or skills • Got used to tools and equipment • Realized it is not a hard thing to do	• Published paper • Attended conference • Got a more comprehensive view of what researchers do

Student B (two or more): "This research stuff like helped me be more a physicist because like… I think… After this past summer, we got our first paper is done which is really good, my name is on it. And it's like I've made me feel really proud and more like okay I can definitely see me doing more of this stuff down the line and really boost my confidence up as a physicist for sure."

4.6 Conclusions

According to SCCT, students' experiences shape their interest and self-efficacy. After gaining or losing interest, self-efficacy, and outcome expectations, students make career goals and take actions based on their goals [10]. By investigating undergraduate physics majors, I examined the cycle of SCCT works for physics majors, and it is related to the physics identity and integration theory of Tinto.

The factors that affect students to major in physics examined. Students' high school/college science or physics course experience and science media play a significant role in their decisions to be a physics major. These experiences affect their interest and beliefs about being good at science/physics. Having interest and believing their performance shapes their physics identity and help them make career choices in physics. Based on these career choices, they decide to major in physics. This is the first cycle of SCCT and helps us to understand how students make choices to major in physics.

When students start to major in physics, they make new career actions like taking a physics course, attending colloquiums, making connections with other physics majors or physics professors, doing research, or internship. Experiencing every career action shapes students' interest, self-efficacy, and outcome expectations. As a result of these changes, students revise career goals, and they take another action based on the new goals.

In this research, I have aimed to investigate what are the milestones students do and affect them to revise their career goals (Research question #2). That is why I have asked questions to understand their relations with faculty and peers, their research experiences, and their career goals. I found that Gateway to Physics course, upper-level physics courses, and research experiences are the crucial milestones students mentioned changed their relations with peers and faculty, changed their career goals, and helped them to stay in physics. Among these three, I found that research experiences are the most influential in affecting their physics identity and decisions to stay in physics. Since most of the physics majors left physics after the first and second year, meaning after taking physics and/or calculus courses, being successful or failing these courses affect the choices to leave physics. Because of that, I suggest that if students take Gateway courses and start doing research in their first and second year, they will be most likely to stay in physics.

Moreover, I found that the answers to research questions 1 and 3 are related to each other (RQ#1: What are the characteristics of students who stayed in the physics program? RQ#2: What are the differences or similarities of physics majors at a different stage of the program?). Upper-level physics majors are more experienced than first-year and second-year students, and they developed more connections in the department. Because of the experiences and relations, students in the upper-level courses have developed more self-efficacy and physics identity than others. That is why they likely to stay in physics compared to first-year students.

Also, it has been found that almost a quarter of the students have decided to major in physics after taking a college physics course. Since introductory physics courses are a great place to attract other majors into physics, I suggest more research should be a focus on how to make them more alluring.

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5 CONCLUSIONS

The overall goal of this research is to investigate students' persistence decisions and attitudes not only at the course level but also at the program level. This research consists of three parts. The first two evaluate the effects of instructional interventions on students' persistence decisions and attitudes. The last one examines students' persistence decisions and attitudes at the program level and studies physics majors' identity development and retention.

With SCALE-UP implementation, half of the algebra-based physics courses are converted as a SCALE-UP. I have compared the effects of SCALE-UP with Traditional courses. This research shows how interventions can be successful and might have even positive impacts on the areas that are not intended. SCALE-UP intervention aims to improve students learning and attitudes and beliefs about learning physics. In the first years of implementation, SCALE-UP courses resulted in more conceptual learning and success rates than Traditional courses. Over the years, students in SCALE-UP have benefited from the interactive nature of the classes. Besides, the nature of Traditional courses is changed even though it was not planned to do so. Since the same instructors teach both SCALE-UP and Traditional courses, with the SCALE-UP implementation, instructors started to apply interactive teaching techniques in both types of courses, and this resulted in a dynamic change in the department.

Moreover, this results in improvements in students learning and persistence rates in both classroom types. However, only SCALE-UP courses have enhanced learning attitudes in Conceptual Understanding and Problem-Solving categories in CLASS. Despite the effectiveness of the Traditional courses in improving learning and persistence after instructors started to use interactive teaching techniques, they are not effective in improving students' learning attitudes. These results indicate that the integrated lecture/lab approach in SCALE-UP and instructor involvement in all aspects of the course results in a more coherent expert-like framework. Furthermore, this may result in the development of a more integrated expert-like view of Conceptual Understanding and Problem Solving. Universities mostly hesitate to adopt teaching environments like SCALE-UP because of financial reasons. The results of SCALE-UP implementation show that introducing interactive teaching techniques in Traditional classrooms is not enough to improve students' learning attitudes even though they are successful in improving students learning and course persistence. This study also shows that persistence through the course can be achieved with improving students' learning without improving learning attitudes. Even though students do not believe they are learning better through the course, they still put enough effort to pass the course. However, since learning attitudes is not just affect persistence through the course, they are also influential in students' decisions to stay in STEM [1]. Therefore, I strongly suggest that departments make use of integrated environments like SCALE-UP to improve learning attitudes. In

In the second intervention, three-hour traditional lab portions of the calculus-based introductory physics courses are converted into one-hour tutorials and two-hour inquiry-based experiments. With this lab reform, it has been found and reported in Chapter 3 that by only redesigning the lab portion of the classes, it is possible to improve conceptual learning and persistence rates. However, to improve students' attitudes and beliefs about physics, universities need to implement more comprehensive reforms than just changing the lab portion of the courses. To improve students' learning attitudes, students might need to see courses as more coherent, like SCALE-UP courses. Ali and Thoms have analyzed the lab evaluation survey to figure out the reasons why learning attitudes did not improve with Redesigned labs [2]. They suggested that if tutorials can be aligned more with the lecture part, and students might see them as coherent and might help them to have more positive attitudes toward tutorials and learning physics. After their work, the tutorial part is aligned more with the lecture part of the courses. As future work, PER group plans to evaluate the effects on learning attitudes of lab reform after the alignment of tutorials. However, SCALE-UP and lab reform studies have limitations such as with these investigations, measuring their effects on persistence in the major is not possible since they were course level measurements. Also, if these studies contained qualitative measures, students' attitudes and beliefs could be examined more in-depth, and these could give more understanding about how students' career decisions are influenced by these interventions.

Undergraduate physics majors' decisions to stay in physics characterized in the fourth chapter. In this work, physics majors from the first year to senior are interviewed, and their experiences, identity development, integration to the departments are examined. It has been found that the Gateway to Physics course, upper-level courses, and doing research are the most significant milestones that affect students' persistence in physics. Participants reported that these are the courses that help them build relations with their peers and professors in the physics and astronomy department. They stated that as a result of being connected to the department, especially with professors, they feel recognized as a good physics student.

Moreover, the feeling of being recognized improved their physics identity and persistence in physics. Most students stated that they value more being recognized by professors as a good student compared to being recognized by peers or family. Even though some students said they feel recognized because of the good grades they have, they still looked for verbal confirmation from professors. Students doing research more than a semester are more confident about their performance and felt more recognized by faculty because they had more chances to communicate about their performance with faculty. Overall, we found that students' attitudes and beliefs about learning physics are shaped by their integration to the departments and influence their beliefs to be recognized by professors and physics identity. By improving their beliefs about recognition and physics identity, integration also affects persistence. Since most of the students participating in our study stated that they do not feel much integrated as much as the students who have done two years or more research, departments need to take measures to improve communication between physics majors and professors. Also, all instructors need to think about how to appreciate better students' achievements in the classroom. Even if small verbal verification like saying "good job" is sometimes making a difference in students' life and identity development. Furthermore, undergraduate research experiences for more than two years is not just crucial in improving students' academic integration, physics, identity development, and decisions to stay in physics, but also students gain various skills. That is why departments and institutions need to create more research opportunities and environments, and more students can have access to do research more than just a semester can benefit from these experiences.

In this work, the effects of the two interventions are evaluated, and the retention of physics majors is investigated. Implementing research-based interventions in classrooms or labs are helpful to improve student learning and retention of the courses. The effort of a single instructor can make course interventions successful at addressing improving both students' persistence choices and their attitudes; however, to make changes at the program level, more people's willingness is necessary. Each instructor needs to put effort to improve his/her relations with students. Instructors also need to show their students that they aware and acknowledge their students achievements and then students can feel recognized by the professors more.

Furthermore, students expressed that their relations with professors influence their self-efficacy and persistence choices in physics programs. This finding supports the hypothesis that the reason SCALE-UP classrooms improve learning attitudes is that SCALE-UP classrooms gives more opportunities to improve communications between instructors and students. Thus, in order to improve students' attitudes in traditional courses, instructors need to enhance their communications with students in these classes as well.

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APPENDICES

Appendix A – Rubric for Characterizing the Level of the Inquiry of the Labs

	Question we need to answer in order to characterize?	Provided	Provided w/ guidance or Not Provided
1st Category **Problem/Question** **Description:** Topic of investigation	1. Does manual explicitly state the problem/question/situation of the experiment?		
	2. Does the manual of the experiment do any of the following? a) State the broad goals of the labs rather than explicitly stating the situation. b) Provide the question/problem of the experiment by asking questions. c) Help students to construct the question after giving the topic/without giving the topic.		
Sub-Category of 2nd Investigation of Theory: Prediction **Description:** Asking students what is going to happen in that situation so as to relate them to the broad goals of the experiment	3. Does the manual of the experiment do either of the following? a) Provide prediction questions that help students' ideas to come out about the investigation. b) Ask students to draw prediction graphs in order to increase their level of understanding in the situation giving in the prediction questions.		
2nd Category			

Investigation of Theory **Description:** All prior knowledge necessary to the investigation Note: Having been taught the material in the lecture does not counted as "Provided".	4. Does the manual of the experiment include pages long theory section?		
	5. Does the manual of the experiment do any of the following? a) Ask students to draw free body diagrams in order to clarify/make sense of situation given in the experiment. b) Provide guiding questions to investigate/explore the theory of the experiment on their own. c) Ask explanations while investigating the theory of the experiment.		
3rd Category **Procedures/ Design** **Description:** Experimental procedures students need to execute in order to take data **Note:** Giving which data students should take does not counted as a **"Provided".** Also, giving procedures about how to use a specific software does not counted as a **"Provided"**.	6. Does the manual of the experiment provide step-by-step instructions to follow in order to take data?(Do this… do this kind)		
	7. Does the manual of the experiment do either of the following? a) Provide questions to guide students to investigate which procedures they need to follow in order to take data. b) Ask students to design the experiment and help them in designing by asking questions.		

4th Category **Results Analysis Description:** Interpreting and analyzing the data	8. Does the manual of the experiment provide equations or specific instructions about how to analyze the data?		
	9. Does the manual of the experiment do any of the following? a) Ask students to determine relationship between the concepts. (It could be looking at the tables and making sense of the relation between concepts.) b) Ask students to analyze the results on their own. (It could be graphing and drawing meaning from the graphs.) c) Ask questions about relating the results with their predictions.		
5th Category **Results Communication and Conclusion** **Description:** Understanding the broad meaning of the experiment **Results Communication:** The manner by which data and experimental results are presented **Conclusion:** Summarizing the results of the experiment	10. Does the manual of the experiments directly provide interpretation of the results by itself?		
	11. Does the manual of the experiment do any of the following? a. Provide qualitative reasoning questions in order to help students to interpret the results by themselves. b. Provide quantitative reasoning questions in order to help students to interpret the results by themselves. c. Ask explanations for error calculations (like percentage error or uncertainty calculations) in order to make sense of the results. d. Ask summarizing/concluding questions about concepts. e. Ask summarizing/concluding questions about application of concepts.		

Appendix B - Instructor Survey

1. Please enter your full name

PART A

2. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use traditional lecture?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

3. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you ask questions to the whole class and allow a few of the students to answer as an instructional strategy?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

4. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you ask your students discuss ideas in small groups?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

5. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you ask your students to design experiments/activities?

a. Never
b. Once or twice
c. Several Times
d. Weekly
e. For Nearly Every Class
f. Multiple Times Every Class

6. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you ask your students to work together?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

7. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you solve/discuss quantitative/ mathematical problems?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

8. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you solve/discuss qualitative/ conceptual problems?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

9. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you ask your students to solve/discuss quantitative/mathematical problems?
    a. Never

b. Once or twice
c. Several Times
d. Weekly
e. For Nearly Every Class
f. Multiple Times Every Class

10. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently in class do you ask your students to solve/discuss qualitative/conceptual problems?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

11. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use whole class voting as an instructional strategy (instructor poses questions that are answered simultaneously by the entire class)?
    a. Never
    b. Once or twice
    c. Several Times
    d. Weekly
    e. For Nearly Every Class
    f. Multiple Times Every Class

PART B

12. On tests in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use well-defined quantitative problems (i.e., problems that have one definitive answer)?
    a. Never Used on Tests
    b. Used Occasionally on Tests
    c. Used Frequently on Tests
    d. Used on All Tests

13. On tests in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use open-ended quantitative problems (i.e., problems that do not have one definitive answer)?
    a. Never Used on Tests
    b. Used Occasionally on Tests
    c. Used Frequently on Tests
    d. Used on All Tests

14. On tests in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use novel problems (i.e., problems that are substantially different from examples previously worked)?
    a. Never Used on Tests
    b. Used Occasionally on Tests
    c. Used Frequently on Tests
    d. Used on All Tests

15. On tests in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use multiple choice questions?
    a. Never Used on Tests
    b. Used Occasionally on Tests
    c. Used Frequently on Tests
    d. Used on All Tests

16. On tests in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use conceptual questions?
    a. Never Used on Tests
    b. Used Occasionally on Tests
    c. Used Frequently on Tests
    d. Used on All Tests

17. On tests in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use questions that require students to explain their reasoning?
    a. Never Used on Tests
    b. Used Occasionally on Tests
    c. Used Frequently on Tests
    d. Used on All Tests

PART C

18. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you give quizzes?
    a. Almost in every week
    b. Once in every two weeks
    c. Several over the semester
    d. Never

19. On quizzes in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211**) course, how frequently do you use well-defined quantitative problems (i.e., problems that have one definitive answer)?
    a. Never Used on Quizzes
    b. Used Occasionally on Quizzes
    c. Used Frequently on Quizzes
    d. Used on All Quizzes

20. On quizzes in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use open-ended quantitative problems (i.e., problems that do not have one definitive answer)?
    a. Never Used on Quizzes
    b. Used Occasionally on Quizzes
    c. Used Frequently on Quizzes
    d. Used on All Quizzes

21. On quizzes in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use novel problems (i.e., problems that are substantially different from examples previously worked)?
    a. Never Used on Quizzes
    b. Used Occasionally on Quizzes
    c. Used Frequently on Quizzes
    d. Used on All Quizzes

22. On quizzes in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use multiple choice questions?
    a. Never Used on Quizzes
    b. Used Occasionally on Quizzes
    c. Used Frequently on Quizzes

d. Used on All Quizzes

23. On quizzes in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use conceptual questions?
    a. Never Used on Quizzes
    b. Used Occasionally on Quizzes
    c. Used Frequently on Quizzes
    d. Used on All Quizzes

24. On quizzes in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use questions that require students to explain their reasoning?
    a. Never Used on Quizzes
    b. Used Occasionally on Quizzes
    c. Used Frequently on Quizzes
    d. Used on All Quizzes

PART D

24. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you assign homework?
    a. Almost in every week
    b. Once in every two weeks
    c. Several over the semester
    d. Never

25. On homework in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use well-defined quantitative problems (i.e., problems that have one definitive answer)?
    a. Never Used on Homework
    b. Used Occasionally on Homework
    c. Used Frequently on Homework
    d. Used on All Homework

26. On homework in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use novel problems (i.e., problems that are substantially different from examples previously worked)?

a. Never Used on Homework
b. Used Occasionally on Homework
c. Used Frequently on Homework
d. Used on All Homework

27. On homework in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use multiple choice questions?
    a. Never Used on Homework
    b. Used Occasionally on Homework
    c. Used Frequently on Homework
    d. Used on All Homework

28. On homework in your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you use conceptual questions?
    a. Never Used on Homework
    b. Used Occasionally on Homework
    c. Used Frequently on Homework
    d. Used on All Homework

PART E

29. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211**) course, how frequently do you give worksheets to be completed in class?
    a. Almost in every week
    b. Once in every two weeks
    c. Several over the semester
    d. Never

30. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, when you give worksheets to complete, how often are the students required to work on them in groups?
    a. Never, they always work alone
    b. Occasionally work in groups
    c. Frequently work in group
    d. Always work in groups

31. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, do you ask students to share their work with the rest of the class after they have completed the worksheet?
    a. Yes
    b. No

32. In your **Physics COURSE NAME (1111 Traditional, 1111 SCALE-UP, 2211)** course, how frequently do you grade worksheets?
    a. Always
    b. Most of the time
    c. Half of the time
    d. Less than half of the time
    e. Never

Appendix C - Interview protocol

Please do not use any names or share any information that can identify other people.

Identity

1. What characterizes a physicist in your mind?
2. How do you think one becomes a physicist?
3. Do you consider yourself a physicist? Follow-up with why.
4. How long have you done research? In which field, have you done your research?
5. Has your perception of yourself as a physicist changed as a result of your research experience? How?
6. What do you plan or expect to do after completing your degree?

Self-efficacy

1. Have you become more confident in your abilities in physics while taking the *Research Project course*? How?

Integration

1. Do you think it is important to you personally to build relationships with faculty? Why?
2. Do you think it is important to your career success to build relationships with faculty? Why?
3. Which courses or academic activities do you think have strengthened your communication with the faculty members in the physics and astronomy community? Explain how?
4. Do you participate in any of these club activities (SPS, Women in Physics, AstroPAL)? How do club activities or relationships affect you as a physicist and your career?

5. Which courses or academic activities do you think have strengthened your communication with other students in the physics community?
6. Did you take Gateway course?
7. Did the Gateway course strengthen your communication with other students in the physics community?
8. Have you been a Learning Assistant (LA) in any course? Has being LA changed your perspective as a physicist?

Outcome expectations

1. How much do you think you know about possible career options in physics? Where have you learned about career options? What options do you have as a physics major?
2. Has taking the *Research Project course* changed your perspective on physics as a career? How?
3. What activities or experiences have you done to prepare for that career path?
4. What activities or experiences will you do to prepare for that career path?

Recognition

1. Do you feel you are recognized as a good physics student by your professors/family/friends/classmates?
2. Which one of these is most important to you?