The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #44087

Board 232: Co-teaching in Undergraduate STEM Education: A Strategy to Enhance the Learning and Teaching Environment in Math, Physics, and Engineering Courses

Dr. Burcu Ozden, Pennsylvania State University

Dr. Burcu Ozden holds a master's degree in physics education as well as a doctorate in physics. She is currently an assistant professor at Penn State Abington. Her work focuses on defects, exciton-polaritons, radiation studies, engineering education, and the integration of sustainability in engineering.

Dr. Michael Kagan, Pennsylvania State University

Michael (Mike) Kagan is an associate professor of physics at Penn State Abington. He received a Ph.D. in Physics from the Pennsylvania State University. Dr. Kagan's research interests are diverse and include Quantum Gravity and Cosmology, Electric Circuits and Algebraic Graph Theory; Physics Education

Dr. Matthew A. Fury, Pennsylvania State University

Dr. Matthew Fury is a Professor of Mathematics and Division Head of Science and Engineering at Penn State Abington. He has a Ph.D. in Mathematics from Bryn Mawr College. Dr. Fury's research interests are in functional analysis, operator theory, and ill-posed problems. He has over 10 years of experience teaching Calculus, Linear Algebra, and Differential Equations. In more recent years, Dr. Fury has shifted focus to service in administration. He is especially interested in developing impactful practices and programs that support the success of underrepresented groups in STEM education.

Dr. Andrei Blinkouski, Pennsylvania State University

Dr. Andrei Blinkouski is an Associate Teaching Professor of Physics at Penn State Abington. He earned his Ph.D. in physics and mathematics from Belarusian State University in Minsk, Belarus. His research interests include gravitation, cosmology, fluid mechanics, and physics education. In addition, Dr. Blinkouski is also involved in research with undergraduate students at Penn State Abington, helping young people choose their path in science and engineering.

Dr. Zafer Hatahet, Embry-Riddle Aeronautical University, Prescott
Dr. John Majewicz, Pennsylvania State University

John Majewicz is an Assistant Teaching Professor of Mathematics at Penn State Abington. He received a Ph.D. in Mathematics from the Temple University under the guidance of Dr. Doron Zeilberger.

Co-teaching in Undergraduate STEM Education: A strategy to enhance the learning and teaching environment in Math, Physics and Engineering Courses

Burcu Ozden[1], Andrei Blinkouski[1], Matthew Fury[1], Michael Kagan[1], John Majewicz[1], Laura McGhee[2], Zafer Hatahet[3]

[1]Science and Engineering Division, Penn State Abington, Abington, PA, 19001, USA

[2]Institutional Researcher, Penn State Abington, Abington, PA, 19001, USA

[3]College of Arts and Sciences, Embry-Riddle Aeronautical University, Prescott, AZ, 86301, USA

Abstract
At its essence, collaborative efforts define STEM research. Likewise, one can anticipate that fostering interdisciplinary collaboration in STEM education will yield positive outcomes. A recent NSF S-STEM grant has empowered us to formulate and implement integrated courses at Penn State Abington, covering subjects in mathematics, physics, and engineering.

Despite calculus being a prerequisite for physics across many undergraduate programs in the United States, a significant number of students fail to maintain crucial mathematical skills, impacting their success in physics. Notably, concerns have arisen from engineering majors who express displeasure in being required to take math classes as part of the engineering curriculum. While math and engineering professors may find this objectionable, it is a reasonable concern, given that mathematics is often taught as an abstract discipline, and students need to grasp its relevance to their future roles as engineers.

To address this issue, we have initiated the development of an Integrated Curriculum, starting with two pairs of courses: MATH 140 (Calculus with Analytic Geometry I) paired with PHYS 211 (General Physics: Mechanics), and PHYS 212 (General Physics: Electricity and Magnetism) paired with EE210 (Electrical Engineering: Circuits and Devices). This paper provides a comprehensive overview of this initiative, delineating its rationale and potential challenges associated with integrated curriculum.

Additionally, we will delve into survey data collected bi-weekly from students, capturing their opinions on these integrated courses. Our aim is not only to provide insights for instructors new to or contemplating co-teaching but also to guide those who have already embraced co-teaching by presenting research-backed practices and sharing our experiences for potential adjustments.

I. Introduction

Penn State Abington stands out as the most diverse campus within the Penn State University system, boasting economic, racial, and ethnic diversity. Among its 3100 undergraduate students, around 39% are recipients of Pell grants, and 29% are pursuing majors in STEM fields. The campus faces challenges as a significant number of students come from K-12 systems that haven't adequately prepared them for college-level math and science. Additionally, many students work over 20 hours per week, often off-campus, and spend an average of 2 hours daily commuting on public transportation.

These circumstances contribute to lower retention and graduation rates, particularly affecting students from racial and ethnic minorities who are already underrepresented in the STEM workforce. Notably, recent data shows that only about 45% of all majors manage to graduate with a bachelor's degree within four years. The situation is more challenging for specific groups, such as engineering students, where fewer than 38% graduate in four years, and only 14% of African American engineering students starting at Abington achieve the same.

To enhance the retention of engineering students and the educational experience at Penn State Abington, we have proposed a four-year program tailored for students displaying both high academic potential and financial need. Our NSF S-STEM funded program awards a total of 96 scholarships to 48 unique recipients pursuing engineering majors during their freshman and sophomore years. Additionally, participants in this program will benefit from a specialized curriculum, engaging in two pairs of integrated courses: MATH 140 paired with PHYS 211, and PHYS 212 paired with EE210. This approach is designed to foster a sense of community among students and provide them with a more meaningful education, where abstract mathematical concepts gain practical significance in physics, and challenging physics concepts are elucidated through applications in engineering. Moreover, students enrolled in this program receive support through peer tutors, dedicated academic advisers and faculty mentors, and tailored mentorship from alumni engineers possessing industry experience. These additional resources aim to further bolster the academic and career success of the students involved.

The program aims to offer valuable insights to faculty and institutions currently engaged in the active redesign of STEM curricula, with a specific focus on engineering curricula. The proposed initiative heavily draws upon extensively documented high-impact practices [1], including Freshman Interest Groups (FIGs), proactive advising, peer mentoring, and experiential learning. Additionally, our proposal suggests the integration of interdependent courses, linking mathematics with physics and physics with electrical engineering. This strategic integration aims to enhance efficiency and generate greater interest among students, allowing them to experience real-time applications of theoretical subjects.

This approach represents a relatively innovative method, particularly within the context of institutions serving underserved populations with comparatively low retention and graduation rates.

The paper is organized as follows. Section II outlines the project's aims and goals. In section III, we present the methodology, including the outline of assessment metrics, both qualitative and quantitative; the timeline of the project; and course descriptions and the philosophy behind the design of the integrated curricula. The first results are provided in section IV, followed by their discussion in section V, which also includes the transpired project limitations and changes that we are planning to implement for the second cohort. The conclusions are given in section VI.

II. Motivation

The primary motivation behind exploring co-teaching in interdisciplinary STEM courses in this project is to enhance student learning outcomes by leveraging the diverse expertise of multiple instructors. This approach aims to provide students with a more comprehensive and interconnected understanding of STEM topics, hence improving the students' retention at Abington College. Co-teaching is motivated by the recognition that certain interdisciplinary STEM topics may require expertise from multiple disciplines. This teaching method will allow for the bridging of disciplinary gaps and the creation of a more holistic educational experience providing students with a better learning environment. Co-teaching in interdisciplinary STEM courses is driven by the goal of preparing students for real-world challenges that often require a combination of skills and knowledge from various STEM fields. Our objectives closely coincide with the goals of our NSF project, which aims to enhance the retention and educational experience of engineering students while also equipping them for success in their professional career.

Another motivation of co-teaching in interdisciplinary STEM courses is to foster a collaborative teaching environment, encouraging instructors from different disciplines to work together, share insights, and contribute to a cohesive educational experience for students. With these objectives at the forefront of our focus, this paper aims to explore: 1) the methods and techniques employed to establish an interdisciplinary environment, 2) the primary advantages and obstacles encountered by instructors when implementing co-teaching in interdisciplinary STEM courses, and 3) the perspectives and experiences of students in these courses.

III. Methodology

A. Assessment metrics

The first stage of our project was assessed following a mixed-methods approach, integrating both quantitative and qualitative data. Below outlines the primary metrics we used to gain initial findings related to the first cohort of the program. These include student grades, teaching evaluations, and biweekly student surveys.

1. Students' Grades: Students' grades were collected and analyzed to determine if there was a significant improvement or achievement in relation to the objectives of the project. The analysis considered various factors, such as the distribution of grades, the average course grade, students' cumulative grade, and the percentage of students achieving a predetermined grade threshold. In this project, we have analyzed the improvement in student academic performance by comparing the average GPA and credit units earned between program participants and a matched control group. The control group was selected by matching with the STEM students on specific criteria. Control group students were matched based on demographic information, current academic program, high school performance and receiving credit for a high-level high school math course. Developing a control or comparison group enhances the validity of the study by attempting to controlling for potential confounding variables.

2. Teaching Evaluations: At the conclusion of each semester, students are required to provide evaluations of their teachers' performance and the overall class experience. This feedback was synthesized to assess the effectiveness of the course from the student's perspective. These evaluations helped in understanding the impact of the project from the students' perspective and identified areas for improvement. Some of these responses speaking to the integration part of the courses are provided in Appendix A.

3. Student Surveys: Biweekly surveys were implemented for the Fall 2023 combined course of EE 210 and PHYS 212. These surveys, or exit tickets, were designed to gather feedback from students at regular intervals. Instructions provided to students indicated that the survey results would be utilized to enhance the structure and delivery of the combination course. These surveys allowed for the collection of real-time, qualitative data on student engagement, understanding, challenges, and the effectiveness of teaching methods. The survey responses were analyzed to track changes in student perceptions and experiences throughout the duration of the project.

This triangulation of data sources – grades, evaluations, and surveys – provided a comprehensive assessment of the success of the initial stage of the project, combining objective measures of academic performance with subjective feedback on the teaching and learning experience.

B. Timeline

Our project commenced in the summer of 2022, initiating comprehensive preparation of faculty members for course design. This groundwork was critical for the successful integration of the curriculum. The inaugural cohort began in Fall 2022, featuring a combined curriculum of the Penn State courses MATH 140 and PHYS 211. This integrated course marked the first practical implementation of the project's educational approach.

In the following semester, Spring 2023, there were no integrated courses scheduled for the students. However, to maintain the continuity of the project's objectives and to align with students' academic goals, professional advisors played a pivotal role. They ensured that students were enrolled in courses relevant to their intended majors, thus preserving the project's overarching educational strategy. As much as possible, the participating students were block-scheduled in the same classes, such as MATH 141 (Calculus with Analytic Geometry II).

The project's second phase commenced in Fall 2023 with the program’s Fall 2022 cohort entering their second year. In this phase, the integrated curriculum consisted of the Penn State courses PHYS 212 and EE 210, marking another step forward in the project's commitment to innovative and interdisciplinary education in STEM fields.
The second cohort will commence in Fall 2024. This timeline reflects the project's phased approach, allowing for evaluation and adaptation of the integrated curriculum based on the experiences and outcomes of each cohort.

Semester	Cohort 1	Cohort 2	Cohort 3	Cohort 4
SP 2022	Curriculum Design			
FA 2022	**MATH 140/PHYS 211**			
SP 2023	Data Analysis			
SU 2023	Curriculum Design			
FA 2023	**PHYS 212/EE 210**			
SP 2024	Data Analysis			
SU 2024		Curriculum Review		
FA 2024		**MATH 140/PHYS 211**		
SP 2025		Data Analysis		
SU 2025		Curriculum Review	Curriculum Review	
FA 2025		**PHYS 212/EE 210**	**MATH 140/PHYS 211**	
SP 2026		Data Analysis	Data Analysis	
SU 2026			Curriculum Review	Curriculum Review
FA 2026			**PHYS 212/EE 210**	**MATH 140/PHYS 211**
SP 2027			Data Analysis	Data Analysis
SU 2027				Curriculum Review
FA 2027				**PHYS 212/EE 210**
SP 2028				Data Analysis
SU 2028	**FINAL REPORT**			

Figure 1. The timeline of the project by semester.

C. Course Descriptions, Curriculum Design Philosophy and Implementation

In this section, we outline the regular MATH 140, PHYS 211 and 212, and EE 210 courses and provide our readers with an understanding of how the integrated courses differ from the regular ones. We highlight some of the inherent challenges encountered when merging these two courses, considering the specific nature and requirements of each existing course. We also describe the philosophy behind the curriculum design and the way it was implemented. Note that in each pair of integrated courses, one course – when taught in a regular format – is a pre-requisite of the other one. We'll refer to those two as "pre-course" and "post-course" respectively.

1. MATH 140/PHYS 211

In accordance with NSF S-STEM grant master plan, 12 students of the first cohort (S-STEM FIG) were enrolled in MATH 140 and PHYS 211 courses during the fall 2022 semester of their freshman year. However, for the first time, two courses were block scheduled into one "virtually" integrated MATH 140/PHYS 211 course that was taught jointly by mathematics and physics professors in one classroom for 9 contact hours each week. We used "virtual" integration rather than creating a formally new experimental course because: (a) creating new courses requires a significant amount of time for approval at Penn State, where the process of curricular development is centralized and involves all 20 undergraduate Commonwealth campuses; (b) it may have potential negative effects on the transfer of credits to other institutions and the process of changing majors within Penn State system.

It should be noted that both MATH 140 and PHYS 211 are foundational courses ("gateways") for many science and engineering majors at the Penn State University and important prerequisites for later work in many STEM disciplines. MATH 140 (4 contact hours) is an important building block in the education of any professional who uses quantitative analysis and includes standard introductory topics in differential calculus, integral calculus and their applications. PHYS 211 (5 contact hours) is a calculus-based introduction to classical mechanics, and laboratory exercises are an integral part of this course. PHYS 211 covers the following topics: kinematics, dynamics, laws of conservation, and their applications. Moreover, both MATH 140 and PHYS 211 are essential for the Entrance to Major (ETM) process in science and engineering majors at Penn State where students are required to complete a certain set of courses and acquire a certain GPA before they are admitted into a specific major of their choice.

At Penn State, MATH 140 is a co-requisite of PHYS 211. Nevertheless, students are generally strongly encouraged to complete MATH 140 before attempting PHYS 211, as mastery of differential calculus is already required to understand the early topics of PHYS 211 related to kinematics. Only students who took calculus in high school may take MATH 140 and PHYS 211 concurrently, but such students typically make up a small fraction of engineering pre-majors at Penn State Abington.

The virtually integrated MATH 140/PHYS 211 course was taught in person three times per week (3 contact hours every class session), primarily in a studio-style physics lab classroom, which fostered a collaborative and cooperative learning environment. In addition, studio-style teaching allowed instructors to easily combine lectures, labs, recitations, and other learning activities within a single class session, furthering the goals of integrated curriculum in the MATH 140/PHYS 211 course. Also, two peer mentors participated in the course (three at the beginning of the semester). Each of them was available for 4 hours per week: 2 hours for in-class activities (recitations, labs, etc.), 1 hour for in-person tutoring, and 1 hour for tutoring via Zoom. In addition, the course included a series of short video tutorials covering topics in basic mathematics, which were posted on Canvas (Learning Management System at Penn State) for the students' review, if necessary. Since many Penn State Abington pre-engineering majors have highly variable mastery of high school level algebra and trigonometry, the idea was to predict topics from pre-Calculus where students typically struggle in a Calculus course. To maintain consistency and continuity, the same textbooks were used in the virtually integrated MATH 140/PHYS 211 course as those used in the traditional MATH 140 and PHYS 211 courses at Penn State Abington: “Calculus: Early Transcendentals” by James Stewart, Daniel K. Clegg, Saleem Watson [2] for MATH 140, and “Fundamentals of Physics” by David Halliday, Robert Resnick, Jearl Walker [3] for PHYS 211.

Details of integrated curriculum of the MATH 140/PHYS 211 course, including a weekly schedule of topics in the course, can be found in Appendix B. As one can see, MATH 140 topics dominate the first third of the semester, while PHYS 211 topics dominate the last third. However, complementary correlations between the topics of the MATH 140 and PHYS 211 curricula in the integrated curriculum are built around two main connection points:

1. Once students in the integrated course have mastered the core topics in differential calculus at the beginning of the course, they can immediately apply their knowledge of differential calculus to the first topics in mechanics (1D kinematics, and 2D & 3D kinematics later). At the same time, some physical problems in kinematics (average characteristics of motion, derivation of the equations of motion, graphical analysis, etc.) prepare the students for and emphasize the necessity of the future topics in MATH140 related to the applications of differentiation (chapter 4 of [2]) and integrals (chapter 5 of [2]). In addition, in parallel with the topics in kinematics, the students are introduced to

further applications of differential calculus to the natural and social sciences (physics, chemistry, biology, economics, etc.; see chapter 3 of [2] for more details).

2. After completing the main topics in integral calculus (chapter 5 of [2]), the students are immediately exposed to the applications of integral calculus in mechanics, including the problems of calculating the work and potential energy functions (chapter 7 & 8 of [3]), the center of mass of solid bodies (chapter 9 of [3]), and rotational inertia (chapter 10 of [3]). At the same time, some topics in integral calculus (net change theorem, average value of a function, etc.) can help the students deepen their understanding of the topics in PHYS 211 (1D kinematics, etc.) covered earlier in the course.

This integrated curriculum was devised to form both horizontal and vertical connections between the two academic disciplines by weaving related topics, concepts, and applications together. Overall, it was designed to create a more holistic learning environment for the S-STEM FIG students in the MATH 140/PHYS 211 course and make their learning more relevant and connected to the real world.

2. PHYS 212/EE 210

In the fall of 2023, the EE 210 and PHYS 212 courses were combined for the first time as part of the NSF S-STEM grant. This integrated course was co-taught by two professors for three hours each day, three days a week. The class comprised twelve students in total. Unlike the initial cohort that was taught in the integrated physics and mathematics courses, not all students in this course were participants in the NSF program. Only four students from the original cohort were enrolled in the second integrated course along with other students outside the program. This variation arose because EE 210 is a required course only for specific majors, so not all students from the first cohort needed to take EE 210 to fulfill their graduation requirements. There were two peer mentors in this class both of whom had previously taken PHYS 212 and EE 210 from the same professors. Each tutor was available for 4 hours per week, which was a combination of in-class assistance during labs or problem-solving sessions and office hours. The office hour schedules were coordinated with those of the S-STEM students so that at least one tutor would be available at the times when the S-STEM members would have breaks in between or after classes. Students were encouraged to attend the tutoring sessions even when they did not feel the need for tutoring. The professors also sought feedback from peer mentors regarding students' participations, questions, and concerns.

PHYS 212 is a standard calculus-based introductory Electricity and Magnetism course, which is taught in a studio format at Penn State Abington. The five weekly contact hours are a (flexible) combination of lecture, lab, recitation and other learning activities. The prerequisites for PHYS 212 include MATH 140 and PHYS 211, which are components of the integrated course on this project. Students are required to either complete Calculus II (MATH 141) prior to taking PHYS 212 or to take PHYS 212 and MATH 141 concurrently. Typically, engineering students at Penn State Abington take this course in their third semester.

The EE 210 course, integrating both laboratory and lecture components, focuses on the essential principles of electrical circuit analysis, electronic devices, amplifiers, and transient analysis in the time domain. It introduces key circuit theories and analytical techniques. . Practical skills are developed through hands-on circuit building and measurements, as well as the utilization of circuit simulation software. Moreover, the course teaches students to adeptly use various electrical testing instruments such as voltmeters, ammeters, ohmmeters, and both digital and analog oscilloscopes. EE 210 students are scheduled for 6 contact hours each week. The prerequisite for this course is PHYS 212. Students have the option to take Ordinary Differential Equations (MATH 250) prior to or concurrently with EE 210. Generally, this course is taken by engineering students at Penn State Abington in their fourth semester. While PHYS 212 is a mandatory course for all engineering majors, EE 210 is specifically required for students majoring in electrical, computer, and multidisciplinary engineering. It also counts as a technical elective for Computer Science and Aerospace Engineering majors.

When the decision was made to co-teach the two courses, it was also agreed that students would receive separate credits and grades for each course to fulfill their graduation requirements. If taught independently, students would have needed to attend 11 contact hours per week. However, given the overlap in topics, 11 hours per week seemed excessive for the integrated course. Therefore, in the planning and design phase, instructors chose to merge these hours, reducing them to 9 hours per week by focusing on the topics common to both courses.

Additionally, it's important to note that students are now undertaking two demanding courses that they would normally take in separate semesters. Furthermore, one of these combined courses is a prerequisite for the other. Students in the integrated course also lack the usual level of mathematical preparedness they would have had if they had taken these courses in their standard semesters. The challenges arising from these preexisting conditions are explored in the results section of this paper.

In the process of creating the courses, the professors adhered to a student-centered philosophy and identified common learning outcomes and objectives. Prior to the inaugural fall semester, the professors held weekly/biweekly meetings to devise a strategy, outline assignments for the courses, and compile a list of essential laboratory experiments and activities that would be required to satisfy their original course syllabi and common objectives for the two courses. The topics for the fifteen-week semester were mapped out in a way that concepts in the post-course would reinforce those learned earlier in the pre-course; and concepts in the post-course would create a need-to-know for the concepts and skills in the pre-course. For some key topics and skills, the learning would occur in several iterations, attaining a deeper level of understanding in each occurrence.

This approach often implies a significant reordering of topics compared to the regular courses. For instance, in a regular PHYS 212 course, students learn Ohm's Law in the second third of the semester. In the integrated course, PHYS 212/EE 210, the concepts of electric current, voltage, and resistance, as well as their relationship, were introduced on Day 1, so that students could start dealing with circuits and devices right away. This was done at a very superficial level at first and then derived from the first principles much later in the semester. This cross-curricular approach differs significantly from a typical EE 210 course structure, where students are usually presumed to already understand Ohm's law and are directly introduced to its application in circuitry. The co-teaching method in this scenario allows for a more foundational and integrated learning experience.

This method also explicitly demonstrated the ongoing collaboration between instructors to the students, emphasizing the importance of teamwork and presenting each subject area as equally significant. For instance, one professor adopted a big-picture approach, assuming students understood basic concepts and employing a top-down teaching method. In contrast, the other professor was more systematic and deliberate, starting with fundamental concepts and building upwards. By continually analyzing themselves and discussing student work and feedback, they developed a pair of co-taught courses that were truly collaborative in content and objectives. Meetings with educational specialists provided insights into effective practices and areas for improvement. Some of these suggestions were implemented immediately, while others are planned for future iterations of the course. Additionally, biweekly student surveys were conducted to gauge what was effective and what needed adjustment, allowing the course to evolve in response to real-time feedback. This process valued students' perspectives, recognizing that their feedback and understanding should drive instructional practices.

The decision was made to use a working calendar as a tool for maintaining organization and ensuring an equitable distribution of content in assignments across both courses. These calendars served as a visual guide for students to understand how the courses complement each other and integrate STEM concepts from math, physics, and engineering. Such calendars for both pairs of integrated courses are provided in Appendices B and C.

IV. Results

A. Student Academic Indicators

Across all traditional measures of academic performance, program participants from the first cohort received higher scores than the comparison group in the first two semesters. The average GPA for Fall 2022 program participants (n = 11) was 3.06 compared with the control group (n = 11) average GPA of 2.77. During the Spring 2023 semester, program participants had a slightly higher average GPA of 3.00 compared to the control group (2.94).

The S-STEM students also earned more term units (credits) per semester. In Fall 2022, program participants earned on average 17 credits compared to 16.81 for the matched group. In Spring 2023, program participants earned 15.95 credits on average compared with only 14 credits earned. For total credits earned, program participants had a higher average number of 49.3 credits versus 46.3 credits earned at the end of their third semester. Note that the Spring and Fall 2023 data are based on ten program participants, as one had left Penn State.

Student outcomes demonstrated encouraging trajectory, with participants showing higher GPAs and earning more credits than their counterparts in the comparison group, suggesting a positive impact on academic performance.

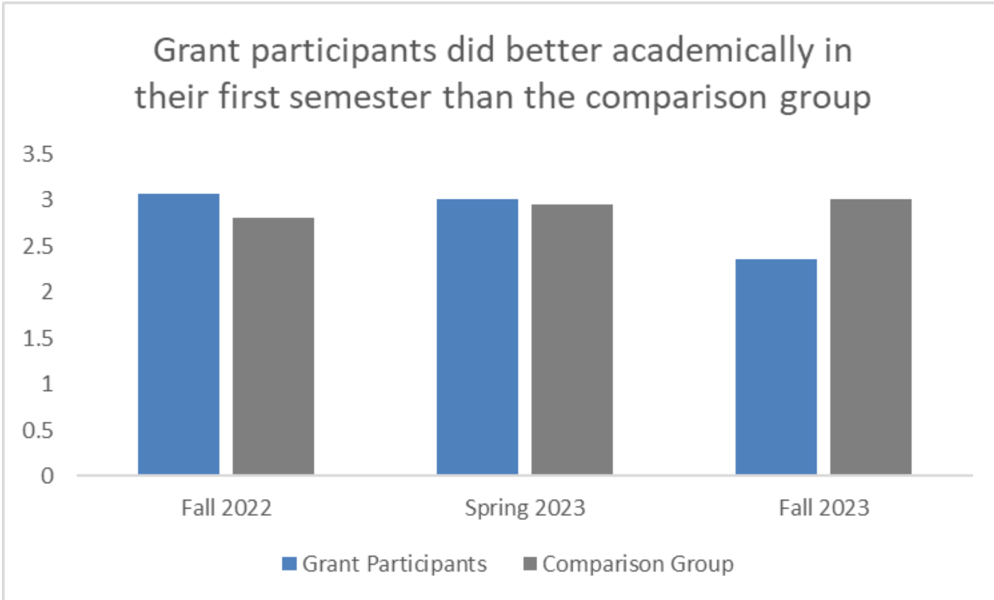

Figure 2. The evaluation of students' GPAs from the start of the NSF S-STEM project shows improved performance during the first two semesters. Note that the Spring and Fall 2023 data are based on ten program participants, as one had left Penn State.

Additionally, the program proved successful in retaining students in STEM fields, with a 90.9% retention rate among participants in engineering majors. Comparatively, 83% of non-program participants were still enrolled in the engineering major from the first year to second year enrollment.

B. Student Surveys:

In terms of curriculum implementation, the program received positive feedback from students for its integration of course, although some challenges were noted in catering to students with varying levels of prior knowledge. A student is quoted:

> *"Having math and physics together makes it easier to make the connection between them and is easier to understand."*

Another student stated:

> *"I like learning both topics together and being able to easily connect the dots between the Physics and EE topics."*

Sentiment analysis of the biweekly exit tickets found that the majority of students' comments were positive or neutral (60% of comments). Many students responded they were able to observe the similarities between both Physics and Electrical Engineering topics, indicating a successful integration of the two subjects in the course. Several student responses indicate a positive reception towards the simultaneous teaching of Physics and EE, suggesting that this method is beneficial for some students. However, 50 percent of students indicated that they felt they were struggling with the combined class structure. Finally, some students mention struggling more with one subject than the other (either EE or Physics), suggesting that the integration of the two subjects might be more challenging for students who have different foundational experiences with the subject matter.

V. Discussion

The analysis of the data provided offers insightful conclusions regarding the effectiveness of the program in several key areas such as student outcomes, curriculum implementation, and comparative success rates.

Overall, initial findings suggest that the program is effectively meeting its objectives in enhancing academic performance, maintaining student enrollment in STEM majors, and alleviating the financial burden on students. The program's teaching approach, as reflected in the NSF-designed courses, is shown to be more effective than traditional methods. However, adjustments to the curriculum may be necessary to address the diverse academic backgrounds of students.

The fact that teaching evaluations for these courses received positive feedback is a favorable indicator of the success of the NSF project described above, for several reasons. The positive teaching evaluations suggest that students were generally satisfied with the courses. This indicates that the integrated teaching approach and the content of the courses were well-received, aligning with the project's goals. High ratings in teaching evaluations often reflect the effectiveness and engagement of the faculty in delivering course material. This suggests that the instructors were successful in implementing the innovative teaching strategies envisioned by the NSF project. The positive feedback in evaluations may also imply that the courses were successful in achieving their learning objectives, which is a key goal of any educational project. This includes fostering a deeper understanding of the material, integrating different STEM fields, and enhancing students' problem-solving and critical thinking skills. Finally, the positive feedback supports the project's approach of integrating courses and using innovative teaching methods. It validates the efforts put into the course design and the pedagogical strategies used. In summary, the positive feedback in teaching evaluations is an encouraging sign that the NSF project is successfully meeting its educational objectives, effectively engaged students, and provided a high-quality learning experience.

Survey results were evaluated from different perspectives. Many students feel that they are successfully mastering both Physics and Electrical Engineering topics. At the same time, there is a need for additional support for students who find the integrated approach challenging. Some students mention struggling more with one subject than the other (either EE or Physics), suggesting that the integration of the two subjects might be more challenging for students who have a weaker foundation in one of the subjects. Overall, the survey results show a mixed reaction to the integrated course. While some students appreciate the combined teaching approach and feel confident in their learning, others struggle with the integration of the subjects and believe they would benefit from separate courses. This feedback is crucial for course improvement, indicating areas where additional support or adjustments might be needed to accommodate different learning styles and levels of preparedness.

A. Limitations of the Project

The project, which integrates physics, mathematics, and electrical engineering courses, faces several limitations. One limitation of our project is related to its reach of eligible students. While the first integrated course is applicable to many students intending a STEM major (e.g. biology, computer science, mathematics), the audience to which an integrated course in electricity, magnetism, circuits, and devices is narrower. Even within the intentions of our grant, which is to improve retention among Engineering students, the second integrated course is not necessarily relevant to popular Engineering majors such as mechanical engineering, civil engineering, or biomedical engineering. One might argue that the integrated course adds breadth of knowledge for such students, an attribute that is increasingly marketable in the workplace. However, care must be taken to ensure that students are not overburdened at a critical time in their undergraduate studies when they are completing core courses for their intended major. To address this limitation, we might consider developing a third integrated course that caters to mechanical engineering; perhaps one which combines PHYS 212 with a math course on either multivariable calculus (MATH 230) or differential equations (MATH 250), which are required for virtually every engineering major.

The standard introductory physics sequence at Penn State has engineering students take PHYS 211 and PHYS 212 in two consecutive semesters, typically in the spring and fall respectively of the same calendar year. Thus our project's timeline presents a pedagogical/learning challenge, as the participating students would take PHYS 211 and PHYS 212 almost a year apart. One of our objectives for the curriculum revision for the next cohort is to alleviate the issue and provide a framework for students to retain the necessary physics skills from PHYS 211 to PHYS 212.

Another limitation of the project, from an administrative standpoint, is maintaining the delivery of integrated courses. A team-taught course is traditionally a 5- or 6-hour course taught by two instructors. The instructors split the effort, and this does not create a major difference in their normal teaching load. The integrated courses meanwhile are 9-hour courses with blended material from traditional courses. The grant currently accommodates the instructors' teaching loads in the sense that they apply the full nine hours of the integrated course toward their load. Such a practice would be challenging to maintain long-term since it significantly cuts down personnel hours to staff our regular course offerings. To address this, as we refine the integrated courses, we might identify a limited number of lessons that feature both instructors in class on the same day.

Furthermore, the initial allocation of just 9 hours per week for the integrated PHYS 212/EE 210 courses proved insufficient for implementing student-centered approaches effectively. The faculty encountered difficulties in adequately covering the broad curriculum within this constrained timeframe. Integrating various disciplines and course materials into a unified curriculum posed significant challenges, notably in harmonizing the differing objectives and content of each course. The varied preparedness levels of students in the combined course, particularly as one course was a prerequisite for the other, led to difficulties for those lacking essential foundational knowledge. Managing the co-teaching model effectively required a delicate balance of teaching responsibilities and loads between instructors. At semester's end, during teaching evaluations, some students expressed concerns about not having sufficient instructional time with the EE instructor, which may partly stem from difficulties adjusting to the integrated course format, especially for those more familiar with traditional teaching methods. The project's success evaluation, primarily based on student grades, teaching evaluations, and biweekly surveys, may not completely reflect the full scope and impact of the integrated courses.

Overall, while the project shows promise in integrating different STEM disciplines, these limitations highlight areas where improvements are needed to enhance the effectiveness and impact of the integrated courses.

B. Proposed changes

In order to improve the project that integrates physics, mathematics, and electrical engineering courses, we are contemplating a range of enhancements. In our semester meetings, we sought advice from an educational specialist. Based on the challenges we shared, the specialist recommended diversifying our teaching approaches to include flipped classrooms, interactive simulations, and hands-on labs, aiming to accommodate various learning styles. Furthermore, the specialist advised considering the adoption of varied and more adaptable assessment techniques, such as project-based assessments, portfolios, and oral presentations, alongside the conventional exams and quizzes. For example, for future classes we are considering developing projects that require students to apply concepts from both physics and electrical engineering, fostering a deeper understanding of how these disciplines intersect in real-world scenarios.

During the Fall 2023 semester, we gathered five surveys, including the teaching evaluation feedback at semester's end. Moving forward, we're considering the collection of more frequent feedback or the establishment of focus groups to pinpoint areas for improvement and accordingly adjust our teaching methods. We also recognize the value of providing continuous professional development for instructors, enabling them to exchange co-teaching best practices and stay abreast of developments in their fields.

A previously mentioned limitation was the inadequate allocation of class hours for the combined courses, where 9 hours per week proved insufficient. To address this, we're contemplating increasing class time to 11 hours per week, which we anticipate will allow for more student-centered approaches, such as student-led discussions, presentations, and research projects, thereby fostering active learning and critical thinking.

These proposed changes are aimed at overcoming the challenges encountered in the initial stages of the project and at boosting the effectiveness and impact of the integrated courses.

VI. Conclusion

Based on the initial findings presented in this study, it is evident that the NSF S-STEM project at Penn State Abington, involving the integration of Physics and Mathematics and Physics and Electrical Engineering and courses, has achieved notable success in several key areas. The project's innovative approach to STEM education, characterized by the co-teaching of interdisciplinary courses, has yielded positive outcomes in terms of student performance, engagement, and satisfaction.

Firstly, the improvement in student academic performance, as evidenced by higher GPAs and credit attainment among program participants, highlights the effectiveness of the integrated curriculum in enhancing students' academic success. The retention rates in STEM majors, particularly in engineering, further attest to the project's ability to maintain student interest and commitment to STEM fields. The reduced need for employment among program participants, likely due to the scholarship component of the program, indicates a significant impact on students' ability to focus on their studies. This is a critical factor in fostering an environment conducive to academic success.

Additionally, the curriculum's positive reception by both professors and students points to its effectiveness in promoting hands-on learning and critical thinking, key components of STEM education. However, the challenges faced by some students, particularly regarding varying levels of preparedness, suggest a need for continued adaptation and improvement of the curriculum to cater to diverse learning needs. The teaching evaluations, being positive, serve as a strong testament to the success of the project. They reflect not only the efficacy of the teaching methods and course content but also the capability of the faculty in engaging and inspiring students. In conclusion, the NSF S-STEM project demonstrates a promising model for interdisciplinary STEM education. Its success in improving academic outcomes, retaining students in STEM majors, and receiving positive feedback from participants underscores the value of integrated, innovative approaches in higher education. While there are areas for enhancement, particularly in addressing the diverse academic backgrounds of students, the project sets a strong foundation for future endeavors in STEM education reform. Going forward, the insights gained from this project can guide the development of similar initiatives, ultimately contributing to the advancement of STEM education.

Acknowledgements
The authors are grateful to Samir Ouzomgi for being instrumental in writing the proposal and being the PI during the first year of the project.

References:
[1] J. Froyd and M. Ohland, "Integrated Engineering Curricula," *Journal of Engineering Education,* vol. 94 (1), pp. 147-164, Jan. 2013.
[2] J. Stewart, D. K. Clegg, and S. Watson, *Early Transcendentals*, *9th Edition*, Cengage 2021
[3] D. Halliday, R. Resnick, and J. Walker, *Fundamentals of Physics Extended*, *10th Edition*, Wiley 2013

Appendix A. Students comments speaking to the integrated aspect of the two courses, MATH 140/PHYS 211 and PHYS 212/EE 210.

MATH 140/PHYS 211
"Many examples per lecture helped me understand the topic."

"helpful examples and good teaching pace"

"This course was very manageable and along with Physics was the perfect amount of Calculus."

"have better timing for each unit"

"A change to the class duration would be nice."

"We also ran a little behind schedule but understandable."

PHYS 212/EE 210
"I don't know whether or not the response is due to the integrated classes with physics. I feel like I would have done better if the classes were separated."

"I've had a great learning experience in regards to feedback, materials, learning activities, peer interactions, instructor interactions, etc. The whole course has been very enjoyable, although still by far the hardest course I've taken."

"It felt like we should have done more EE in the beginning of the semester to get the basics of the course inorder to help us succeed later on due to using those topics throughout the whole semester."

"This is a bit of a repeat from my responses for EE210, since this course is integrated along with it, but again I will say there are almost no negatives in my opinion."

"this course, as it was a combined course with EE it’s hard to follow both."

Appendix B. Weekly Schedule of Topics for the integrated MATH 140/PHYS 211 course (Penn State Abington, Fall 2022 Semester)

Table Legend:
The virtually integrated MATH 140/PHYS 211 course:

M140 = MATH 140 - Calculus with Analytic Geometry I (in black color)
P211 = PHYS 211 - General Physics: Mechanics (in blue color)

Textbooks:
M140: Calculus: Early Transcendentals, 9th Edition, by James Stewart, Daniel K. Clegg, Saleem Watson, Cengage 2021 [2]
P211: Fundamentals of Physics Extended, 10th Edition, by David Halliday, Robert Resnick, Jearl Walker, Wiley 2013 [3]

Week	Day	Lecture Topics	Hours (MATH140)	Hours (PHYS211)
1	M	Syllabi Review. Introduction to the MATH140/PHYS211 course	1.5	1.5
	W	M140 Chapter 1: 1.3 New Functions from Old Functions, 1.4 Exponential Functions	3	0
	F	M140 Chapter 1: 1.5 Inverse Functions and logarithms. P211 Chapter 1: Units and Measurements	1	2
2	M	M140 Chapter 2: 2.1 Tangent and Velocity Problems, 2.2 The Limit of a Function	3	0
	W	M140 Chapter 2: 2.3 Calculating Limits Using the Limit Laws, 2.5 Continuity	3	0
	F	M140 Chapter 2: 2.6 Limits at Infinity; Horizontal Asymptotes P211 Chapter 1: Units and Measurements	1	2
3	M	*Labor Day (No Classes)*		
	W	M140 Chapter 2: 2.6 Limits at Infinity; Horizontal Asymptotes (continued)	3	0
	F	M140 Chapter 2: 2.7 Derivatives and Rates of Change, 2.8 The Derivative as a Function. P211 Chapter 1: Units and Measurements; Uncertainties in Measurements	1	2
4	M	M140 Chapter 3: 3.1 Differentiation of Polynomials and Exponential Functions, 3.2 The Product and Quotient Rules	3	0
	W	M140 Exam 1 M140 Chapter 3: 3.3 Derivatives of Trigonometric Functions, 3.4 The Chain Rule	3	0

	F	M140 Chapter 3: 3.5 Implicit Differentiation P211: Physics Lab 1	1	2
5	M	M140 Chapter 3: 3.6 Derivatives of Logarithmic and Inverse Trigonometric Functions	3	0
	W	M140 Chapter 3: 3.10 Linear Approximation and Differentials, Special Topics: Applications to Physics, Relative Error P211 Chapter 2: Motion Along a Straight Line	1	2
	F	P211 Chapter 2: Motion Along a Straight Line, Chapter 15: Simple Harmonic Motion, Special Topic: Antiderivatives in 1D Kinematics	0	3
6	M	P211 Chapter 2: Motion Along a Straight Line (Motion with Constant Acceleration)	0	3
	W	P211 Chapter 2: Motion Along a Straight Line (Free-Fall Motion)	0	3
	F	P211: Physics Lab 2	0	3
7	M	M140 Chapter 3: 3.7 Rates of Change in the Natural and Social Sciences (Physics, Chemistry, Biology, Economics, Other Sciences) P211 Chapter 3: Vectors	1	2
	W	M140 Chapter 3: 3.7 Rates of Change in the Natural and Social Sciences (continued) P211 Chapter 3: Vectors	1	2
	F	M140 Chapter 3: 3.8 Exponential Growth and Decay, Special Topic: Radioactive Decay P211 Chapter 3: Vectors	1	2
8	M	M140 Chapter 3: 3.9 Related Rates, Special Topic: Applications to 2D Kinematics P211 Chapter 3: Vectors P211: Physics Lab 3	1	2
	W	M140 Chapter 4: 4.1 Maximum and Minimum Values P211 Chapter 4: Motion in Two and Three Dimensions	1	2
	F	M140 Exam 2 P211 Chapter 4: Motion in Two and Three Dimensions	1	2
9	M	M140 Chapter 4: 4.2 The Mean Value Theorem P211 Chapter 4: Motion in Two and Three Dimensions (Projectile Motion)	1	2
	W	M140 Chapter 4: 4.3 Derivatives and the Shape of a Graph	1	2

		P211 Chapter 4: Motion in Two and Three Dimensions (Uniform Circular Motion; Relative Motion)		
	F	M140 Chapter 4: 4.3 Derivatives and the Shape of a Graph P211 Midterm Exam (Chapters 1 through 4)	1	2
10	M	M140 Chapter 4: 4.7 Optimization Problems, Special Topic: Applications to Physics P211 Chapter 5: Force and Motion - I	1	2
	W	M140 Chapter 4: 4.9 Antiderivatives P211 Chapter 5: Force and Motion - I	1	2
	F	M140 Exam 3 P211 Chapter 5: Force and Motion - I	1	2
11	M	M140 Chapter 5: 5.1 The Area and Distance Problems P211 Chapter 5: Force and Motion - I, Chapter 12: Static Equilibrium	1	2
	W	M140 Chapter 5: 5.2 The Definite Integral, 5.3 The Fundamental Theorem of Calculus P211 Chapter 6: Force and Motion - II	1	2
	F	M140 Chapter 5: 5.4 Indefinite Integrals and the Net Change Theorem, Special Topic: Applications to 1D Kinematics P211: Physics Lab 4	1	2
12	M	M140 Chapter 5: 5.5 The Substitution Rule P211 Chapter 6: Force and Motion - II, Special Topic: Optimization Problem in Dynamics	1	2
	W	M140 Chapter 5: 5.5 The Substitution Rule (continued) P211 Chapter 6: Force and Motion - II, Chapter 13: Gravitation	1	2
	F	M140 Chapter 6: 6.1 Areas between Curves P211 Chapter 7: Kinetic Energy and Work (Calculating the Work and Potential Energy using integral calculus)	1	2
13	M	M140 Chapter 6: 6.2 Volumes P211 Chapter 7: Kinetic Energy and Work, Chapter 13: Gravitational Potential Energy	1	2
	W	M140 Chapter 6: 6.3 Volumes by Cylindrical Shells P211 Chapter 8: Potential Energy and Conservation of Energy	1	2
	F	M140 Chapter 6: 6.5. Average Value of a Function, Special Topic: Applications to 1D Kinematics	1	2

		P211 Chapter 8: Potential Energy and Conservation of Energy		
14		*Thanksgiving Holiday (No Classes)*		
15	M	P211 Chapter 9: Center of Mass and Linear Momentum, Special Topic: Calculating the Center of Mass of Solid Bodies using integral calculus	0	3
	W	P211 Chapter 9: Center of Mass and Linear Momentum, Special Topic: Collision and Impulse P211 Physics Lab 5	0	3
	F	P211 Chapter 10: Rotation	0	3
16	M	P211 Chapter 10: Rotation, Special Topic: Calculating the Rotational Inertia using integral calculus	0	3
	W	P211 Chapter 11: Rolling, Torque & Angular Momentum	0	3
	F	P211 Chapter 15: Oscillations P211 Physics Lab 6	0	3

Appendix C. Weekly Schedule of Topics for the integrated PHYS 211/EE 210 course (Penn State Abington, Fall 2023)

The figure below presents the provisional class schedule for the combined EE 210 and PHYS 212 courses in Fall 2024. The schedule uses color coding for ease of understanding: yellow highlights indicate topics covered by the EE instructor for EE 210, blue highlights denote pure Physics lectures, and green highlights are for mixed classes. However, in practice, all Monday classes ended up covering mixed topics and were co-taught by both professors.

Legend	PHYS 212	EE 210	Mix
Week	**Monday**	**Wednesday**	**Friday**
1	Introduction Current, Voltage, Ohm's Law Independent and Dependent Sources Resistance, R-circuits	Gravity – Electricity Analogy Coulomb's Law Conductors and Insulators	Quiz 1 Lab 1A. Using DMM as Ohmmeter Measuring a Resistor's VI Characteristics Lab 1B. PHYS 212 - Equivalent Resistance
2	Circuit Analysis Technique: Series and Parallel Power. Energy. Resistors' Color Code Breadboards. In-class group work (30 min)	Electric Field (EF). EF due to PC's EF due to distributed charges	Quiz 2 Lab 1B. EE 210 Lab 1
3	4-Sep NO CLASSES Happy Labor Day!	Visualization of EF Electric Field Lines	Quiz 3 Kirchhoff's Laws, Ad Hoc Circuit Analysis Voltage and Current Division
4	Lab 2. Potentiometers Voltage and Current Division(Cont) Potentiometers and Modeling Practical Sources, Source Transformation	Electric Flux Gauss' Law	Exam I Phys Lab 3. Practical Sources
5	Lecture: Source Transformation uction to Multisim [PM] Lab 4 Circuit Simulations Node Analysis	Electric Potential Energy Electric Potential (EP) due to PC's EP due to distributed charges	Exam II Phys/EE (Exam I EE) Nodal Analysis/Mesh Analysis
6	Operational Amplifiers Lab 5. Operational Amplifiers I Mesh Anlysis	Visualization of EP Equipotentials	Quiz 5 Lab 6. Overbeck Machine Operational Amplifiers (cont.)
7	Operational Amplifiers (cont.) Lab 6. Operational Amplifiers II	Linearity and Superposition Review	Exam III Phys Thevenin's Theorem Lab 6 (cont.)
8	Practice Multisim (flexible time-wise) Norton's Theorem Maximum power transfer	Magnetic Field. Motion of charges in Magnetic Field. Hall Effect Lab: e/m	Quiz 6 Capacitors. Definitions and basic shapes
9	Capacitors in Circuits Applications of Capacitors , Multisim capacitor IV in class	Biot-Savart Law. Magnetic Field due to currents Visualizing Magnetic Field Lab: compas etc.	Quiz 7 RC-circuits Lab. Data Fitting Theory of RC-circuits. DE
10	Inductors in Circuits Complex Numbers	Electromagnetic Induction. Faraday's Law. Inductors and Inductance. Theory of RL circuits	Exam IV (Exam II EE) RC and RL circuits
11	RC and RL circuits First Order RC and RL Circuits	Electromagnetic Oscillations Theory of LC, RLC circuits Lab: RL, LC, RLC	Exam V Phys First Order RC and RL Circuits EE Lab 7
12	Second Order RLC circuits LC Circuits	Theory of AC circuits Phasor description of AC Circuits Resonance	Quiz 9 Lab Observing IV characteristics of a capacitor Lab 12
13	Sinosoidal Steady State Anlysis	Complex number description of AC Circuits Power in AC Circuits	Exam VI (Exam III EE) EE Lab 8
14	Frequency Response	Maxwell's equations	Quiz 10 Lab 14
15	Steady State Power	Review	Quiz 11 Lab 15
Legend	**PHYS 212**	**EE 210**	**Mix**