Broadening Participation in STEM through High School Physics

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Abstract

Student participation in science, technology, engineering and mathematics (STEM) career pathways requires deliberate efforts to prime the postsecondary pipeline by improving teaching and learning in K-12 settings. Access to and readiness for high quality STEM courses is especially critical for historically underrepresented students, including females and minorities. This study examines a participatory high school physics curriculum project which provided access to hard copy and digital resources, integrated laboratory equipment and comprehensive teacher professional development. Findings from two years of implementation of the *Essential Physics* (EP) curriculum across 42 schools reveal positive impacts on students' interest, enrollment and achievement in high school physics, particularly for females and minorities. Participating teachers suggested that the curriculum's integrated nature promoted student engagement and assisted with concepts for which students have historically struggled. Notable design features of the program are situated in the broader literature on physics education, and opportunities for future research are discussed.

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Introduction

High school physics and algebra are gatekeeper courses for career pathways into engineering or technology disciplines (McCormick & Lucas, 2011; Redmond-Sanogo et al., 2016). To increase the number and diversity of students who choose careers in science, technology, engineering, and mathematics (STEM) fields, high schools must increase and diversify participation and achievement. One coherent strategy is to ensure the curriculum reaches all students by supporting educators to make sustainable instructional changes that encourage active engagement and present frequent applications of concepts, in contrast to traditional, passive methods of teaching in which learning often remains at an abstract level (Arner, 1998; Sadler & Tai, 2001; Scarlatos & Scarlatos, 2008). The goal of an accessible curriculum is to have all students understand physics and engineering in such a way that they can generalize their knowledge to new situations, can engage in conceptual and mathematical modeling of physics related phenomena, and are motivated to continue in discipline-related studies.

In this paper, we present the impact of revising classroom practice to include the use of engaging, hands-on techniques supported by Next Generation Science Standards (NGSS) aligned instructional resources, and teacher professional development (PD) that merges practical interactivity with traditional science content. Training and implementation of the novel curriculum, *Essential Physics* (EP), emphasized the development of enhanced pedagogical content knowledge (PCK) in participating teachers, and prepared them to increase the use of application-oriented, inquiry-based instructional strategies. We describe the role of the PD, the curriculum, and its associated instructional approach in relation to achievement by historically underrepresented groups of students, including female and minority students[1].

Rationale

A competitive US workforce requires students who are sufficiently interested in and prepared to obtain an undergraduate degree in a STEM subject (President's Council of Advisors on Science and Technology, 2010). However, many capable undergraduate students do not

[1] For purposes of this study, we defined minority students as any student who did not identify as White or Asian, including those who identified as Black/African American, Hispanic/Latinx, American Indian/Alaska Native, Native Hawaiian or other Pacific Islander, and Multi-racial.

choose to major in STEM at the postsecondary level. One predictor of entry into a STEM major is a student's interest and participation in advanced level mathematics and science courses in high school (Saw et al., 2018). Various studies have indicated a link between achievement in these courses and the likelihood of selecting a college STEM degree (Tyson et al., 2007; Chen & Weko, 2009; Crisp & Taggart, 2009; Hinojosa et al., 2016). Of particular concern is that the number of students choosing to take STEM major prerequisite courses such as high school physics remains low (DeWitt et al., 2019). This can hamper their efforts to place into other advanced science and mathematics courses (Redmond-Sanogo et al., 2016) and can exclude them from eligibility for many STEM degree programs.

Historically, females and minority students have been less likely to pursue degrees in STEM subjects than white males (Saw et al., 2018; van Aalderen-Smeets & van der Molen, 2018). This may be due to lower enrollment of female and minority students in advanced high school science courses. Lack of participation is particularly notable for physics, although alarmingly, minority student participation in any upper-level science course is low (Tyson et al., 2007; Hinojosa et al., 2016). Although female and minority students have made strides toward closing the physics attainment gap with the advent of selective STEM oriented high school programs (Riegle-Crumb & Moore, 2014), the same opportunities for success may not be readily available in general education high schools (Conger et al., 2009). The standard physics curriculum in many high schools is often isolated from application, and contingent upon high level achievement in mathematics. Providing female and minority students with an engaging physics program that provides a practical application of scientific concepts and integrated support for mathematics may therefore encourage participation and increase overall achievement.

Broadening participation in physics is also likely to require careful consideration of instructional practices. Contemporary approaches to science teaching emphasize the development and use of 21st century skills in the classroom such as communication, collaboration, problem solving, and critical thinking (NRC, 2015). These skills are essential in preparing students to become citizens who are equipped to contribute to society, and may also promote student persistence in STEM education pathways (Carlgren, 2013). Curricular revision and PD are often needed to teach science and mathematics through activities that also engage 21st century skills. In this paper, we describe one approach to revising the curriculum, and offer evidence for its impact on student enrollment and achievement in a science course that may prove to be pivotal for continuation in STEM.

STEM Education and the Workforce

The US workforce must recruit and retain individuals with expertise in STEM subjects including physics, chemistry, mathematics, computer science, engineering, biology and the health sciences to remain competitive in an increasingly STEM-oriented global economy (President's Council of Advisors on Science and Technology, 2010). Currently, these fields are experiencing shortages in both the number and diversity of workers. In fact, women and minorities comprise less than 25% of the STEM workforce (Noonan, 2017; Ong et al., 2018) and are underrepresented in STEM leadership positions in both industry and academia (Wu & Jing, 2013). Minority women have especially low STEM participation, with only 5% nation-wide obtaining STEM undergraduate degrees (Ong et al., 2018, National Center for Education Statistics, 2017).

Research indicated that many female and minority students who do pursue STEM degrees are likely to change their major prior to graduation due to a variety of causes including stereotype threat, societal bias, lack of social support, and the absence of role models (Ivie et al., 2014; National Science Foundation, 2013; Turnball et al., 2019; Whitcomb & Singh, 2020b). These and other causes of what some have referred to as a "leaky pipeline" (Resmini, 2016) emerge in middle and high school, and are manifest in declining science enrollment by female and minority students (Redmond-Sanogo et al., 2016). Over the past 20 years, efforts to broaden participation in STEM have seen a 40% increase in women in STEM fields, but a closer look at the data shows that participation varies widely by discipline. Much of the gains made by women and minorities have been in the health and life sciences. For example, the fields of physics and astronomy are dominated by men; just 22% of physical science researchers are women (Physics World, 2017). Statistics such as these reveal an urgent need to increase preparation and retention efforts in the physical sciences. One strategy may be to examine the content of the curriculum, including its applications to authentic STEM tasks and careers, and to increase the instructional emphasis on collaborative, communication-oriented scientific inquiry.

Reimagining STEM course content

Whereas national science education policy emphasizes 21st century skills that include critical thinking and knowledge transfer as essential to students' preparation for STEM careers (President's Council of Advisors on Science and Technology, 2010), many high school science and mathematics courses use traditional learning strategies such as content and calculation fluency, and do not spend time exploring the application of physics to real world problems (Hestenes et al., 1992). This continues despite evidence that suggests high school course materials that foster these skills and habits of mind benefit students throughout college and into the workplace (Carlgren, 2013). For example, Juuti and Lavonen (2016) found that pedagogical practices such as scientific investigation and the social construction of knowledge through inquiry facilitated students' success during the completion of physics coursework and influenced students' interest in pursuing physics. Interactive computer simulations that spark critical thinking and problem solving have been found to enhance conceptual understanding of physics concepts and improve student's inquiry process skills (Bell & Trundle, 2007; Fan et al., 2018). Inquiry-based instructional strategies implemented in physics classes have been shown to promote greater conceptual understanding (Schalk et al., 2018) and exercises that require generation of solutions for real-world problems have been shown to support students' conceptual transfer (Hofer et al., 2018).

The instructional environment in the classroom can impact motivation and persistence in STEM (Stolk et al., 2018). Physics coursework that fosters self-efficacy and adaptive motivational beliefs, including the idea that success is due to incremental rather than fixed abilities, has been found to increase student success (van Aalderen-Smeets & van der Molen, 2018, Whitcomb & Singh, 2020b). Self-efficacy and motivation for STEM can also be bolstered by student success with introductory mathematics concepts, which pique their interest and motivation in introductory physics courses and can lead to participation in higher level physics (Nix & Perez-Felkner, 2019, Whitcomb & Singh, 2020a).

To be effective in inspiring and preparing diverse groups of students, physics instruction must therefore integrate high quality curriculum resources with instructional practices that improve motivation and interest in pursuing STEM beyond the high school level. Curricular materials should highlight critical thinking around key concepts and include accompanying equipment and instructional resource materials that can promote use of hands-on participation and collaborative discovery. By leveraging students' understanding of physics at the conceptual level, a curriculum can also develop students' understanding of mathematics, rather than requiring mathematical skills as a prerequisite for understanding physics.

Essential Physics

The EP program (Hsu, 2017) and its associated professional development address the twin challenges of improving the physics curriculum and providing resources for teachers that enable them to use engaging, interactive and authentic classroom activities. The curriculum covers standard course content on force and motion, energy and momentum, waves and sound, electricity and magnetism, light and optics, and matter and atoms. These concepts are delivered through digital and hard copy textbooks and are reinforced using associated laboratory investigations. Teachers have access to ancillary materials include lesson plans, slide presentations, student worksheets, in-depth answers to calculation problems, and video resources. The EP curriculum is accompanied by laboratory materials designed specifically for the investigations, and student can access video resources to learn how to set up and use the equipment.

The digital text contains several features designed to assist struggling readers and English language learners. For example, in-text, "pop-up" style definitions help with comprehension of key physics concepts while reading. Videos and interactive simulations provide visual reinforcement of physics concepts and highlight the four STEM content areas. Engineering and technology innovations that incorporate physics principles are included throughout the text and extend into STEM career exploration. Engineering design projects are introduced throughout the book to provide students an opportunity to apply their physics understanding to practical, real-world challenges. The integrated text, digital resources and equipment that incorporate and align physics content with hands-on learning are a key difference between EP and the curricula previously in place in participating schools.

The current study

The purpose of this study was to examine how the use of the EP curriculum influenced student interest in STEM careers, enrollment in high school physics, and achievement in physics, particularly among female and minority students. We addressed the following research questions:

1) How does the EP curriculum influence student interest in STEM careers, particularly among female and minority students?

2) How does the EP curriculum influence student enrollment and achievement in physics, particularly among female and minority students?

3) What factors explain how the EP curriculum influences student outcomes, particularly for female and minority students?

Methods

This study took place over two years in 42 high schools in ten school districts in the mid-Atlantic region of the United States. The mean minority enrollment in participating high schools was 57%, with minority populations ranging from 11% – 99% for these schools. We employed a mixed-method design (Leedy & Ormrod, 2010), using a quantitative, within-group design to examine changes in student interest in STEM careers and enrollment and achievement in physics, and qualitative techniques to analyze responses to open-ended survey items on a teacher questionnaire. Qualitative methods were also used to conduct and analyze data from a purposefully sampled subgroup of participating teachers who were interviewed to examine the factors that helped explain the curriculum's influence on student outcomes. Because the study was conducted in naturally occurring educational settings, we were granted an exempt status for human subjects research from our university's Institutional Review Board.

Sample

With three exceptions, each of the participating schools had just one physics teacher who offered several sections of physics each year; two of the three schools employed two physics teachers and one school had three physics teachers, for a total of 46 teacher participants. Data from the 2017-2018 school year (prior to implementation) served as a baseline measure for student outcomes, with the 2018-2019 school year serving as year one and 2019-2020 serving as year two. At baseline, 1,718 students enrolled in physics in participating schools, 20% of whom identified as female and 18% identified as minority. In year one, the project served 1,990 students, with female and minority participants increasing to 41% and 38%, respectively. In year two, the project expanded to serve 3,093 students, with additional subgroup enrollment increases observed for female (45%) and minority (54%) students.

Measures

To measure student interest in STEM careers, we administered the STEM Career Interest Survey (STEM-CIS; Kier et al., 2014), a valid, reliable measure of secondary students' interest in STEM careers. Composite scores are calculated for each of the four content-area subscales to examine students' interest in STEM. The STEM-CIS was administered in a pre/post manner to examine change over time. Participating students completed the STEM-CIS before and after taking physics to examine program impacts on students' interest in STEM career paths. Student gender and ethnicity were also gathered to allow for examination of differences by subgroup.

Participating schools provided enrollment, demographic and achievement data for participating teachers' physics courses. Final course grades served as our measure of achievement as the participating school districts do not administer a standardized, end of course assessment for physics. Physics course credit was used to evaluate impact on student achievement, where a final course grade of D or above is considered "passing," and students receive credit for the course; for grades lower than D, no credit is earned. Grading techniques remained consistent across project years, although EP resources replaced teacher-made assessments in many cases. Participating teachers often collaborated with their EP peers to ensure that the assessments aligned with the state's standards and with lesson content.

To examine factors that may explain any influence of the EP curriculum on student outcomes, we administered a Teacher Questionnaire that measured teachers' perceptions of the curriculum and its ability to positively impact student interest in STEM careers and achievement in physics. The questionnaire included items that assessed teachers' PCK, their use of instructional strategies that support physics learning, and their confidence in teaching physics. The questionnaire also asked teachers to identify influential components of the EP curriculum. Questionnaires were administered before initial PD was offered to teachers in the summer prior to year one and again at the end of each school year.

We also conducted teacher interviews with a purposeful sample of participating teachers. We were interested in gathering additional data to examine the factors that influenced changes in student outcomes. We consulted with school district secondary science coordinators to identify teachers who used the curriculum with fidelity as well as those who faced challenges with the curriculum to represent a broad scope of implementation. Interview questions focused on the factors that promoted or diminished effective implementation of the curriculum, on the curricular components most often used by teachers, and on how teachers incorporated discussion about STEM careers into their physics classes. Four 30-minute teacher interviews were conducted by phone at the end of year two.

Procedure

School districts and teachers were recruited to participate in this project during the winter/early spring of 2018. Initial professional development occurred through a week-long face-to-face summer institute in July of 2018; at that time, teachers also received a hard copy of the teacher's edition EP textbook, access to curricular digital resources, and several sets of lab equipment to allow completion of physics activities and experiments. Teachers attended a week-long follow-up face-to-face training session during the summer of 2019, in addition to quarterly webinars that focused on specific physics content aligned with teachers' needs (identified through data gathered by the curriculum developer). Teacher surveys were administered prior to initial training in summer 2018 and at the end of the 2019 school year; teachers were surveyed in early March of 2020 due to the anticipated school disruptions and closures due to the COVID-19 pandemic. Student surveys of STEM career interest were administered near the beginning and end of each physics course, and enrollment, demographic, and achievement data were gathered at the end of each school year. Teacher interviews were conducted at the end of year 2, with four teachers agreeing to participate. One teacher had served in the military and one teacher was new to the program in year two, but all teachers interviewed had at least 5 years' experience teaching physics. Two teacher interviewees were male and two were female.

Analytic Approach

Student responses on the STEM-CIS (Kier et al., 2014) were summed for each of the four content strands and content composite scores were used to compare pre/post responses using paired samples *t*-tests. We also conducted between-group differences for male vs. female pre/post differences and non-minority vs. minority pre/post differences using independent samples *t*-tests. We used descriptive statistics to examine the change in student enrollment and achievement in physics from baseline through year two.

We used model-guided and inductive coding qualitative techniques to analyze open-ended responses on the teacher questionnaire to explain perceptions of the program's effectiveness in influencing student outcomes (Patton, 2002). Once teacher interviews were conducted and transcribed, transcripts were uploaded into NVivo qualitative software. Teacher responses were inductively coded at the sentence level using guiding questions that focused on how the EP curriculum impacted student outcomes (Zhang & Wildemuth, 2005). The emerging themes from each guiding question were reviewed, compared to other categories, and revised for clarity.

Findings

Student interest in STEM careers

Our first research question examined student interest in STEM careers. Year one and two pre/post results on the STEM-CIS (Kier et al., 2014) were similar, with non-significant differences on each of the four STEM subscales for the sample overall. In year two, a statistically significant increase was observed for females for the science career subscale. However, for minority students, increases were observed for all four career subscales in year one and for the science, technology and mathematics subscales in year two (see table 1). While only the year one engineering subscale pre-post difference was statistically significant for minority students, non-significant increases remain noteworthy. More importantly, the gap between male and female respondents decreased for all but mathematics in year two, with the gap between non-minority and minority students narrowing for all subscales in year one and for all but science in year two (table 2). Additionally, the statistically significant difference in STEM career interest between non-minority and minority students at pre-course was reduced or reversed for both female and male students at post-course in years one and two (table 3). We believe these findings indicate gains in the critical area of STEM career interest among our female and minority students.

Table 1
Pre- to post-course comparison of means for STEM career interest

	Science subscale			Technology subscale			Engineering subscale			Mathematics subscale		
	Pre	Post	*t*	Pre	Post	*t*	Pre	Post	*t*	Pre	Post	*t*
Year One												
All students	41.4	41.4	0.20	44.0	44.2	-.35	38.7	39.4	-1.2	41.4	41.2	.50
Females	41.2	40.5	1.01	42.1	41.7	.53	35.6	35.4	.29	40.8	40.4	.61
Minorities	40.7	40.9	-.30	43.6	44.0	-.63	37.2	39.3	-2.5*	40.5	41.1	-.88
Year Two												
All students	41.5	42.2	-1.3	43.4	43.4	0.10	39.0	38.3	0.79	40.7	40.8	-.03
Females	41.3	43.5	-2.6*	41.4	42.3	-1.1	35.4	35.6	-.09	40.1	39.5	0.68
Minorities	40.6	41.1	-.53	43.0	43.6	-.54	39.3	38.3	0.75	40.4	40.5	-.01

*Statistically significant at $p < .05$

Table 2

Mean between-group differences on STEM-CIS subscales from pre- to post-course

	Science		Technology		Engineering		Mathematics	
	Mean difference		Mean difference		Mean difference		Mean difference	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Year One								
Male vs female	0.30	1.27	3.57	3.92	5.71	6.53	1.32	1.39
Non-minority vs minority	1.36	0.88	0.75	0.31	2.62	0.04	1.62	0.13
Year Two								
Male vs female	0.33	-1.53	3.47	2.44	5.93	5.66	1.09	3.52
Non-minority vs minority	1.51	1.72	0.72	-0.34	-0.67	-0.04	0.58	0.51

Table 3

Mean between-group differences on STEM-CIS subscales from pre- to post-course by gender and minority identification

	Science		Technology		Engineering		Mathematics	
	Mean difference		Mean difference		Mean difference		Mean difference	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Year One								
Male non-minority vs minority	0.79	0.98	1.12	0.20	1.76	0.26	1.93	0.82
Female non-minority vs minority	2.33	.084	0.98	-0.93	-0.58	0.28	2.70	-0.72
Year Two								
Male non-minority vs minority	1.35	2.24	0.63	-0.86	-1.88	-0.73	0.60	-0.93
Female non-minority vs minority	1.96	1.05	0.78	-1.34	1.35	0.78	0.63	0.20

Student enrollment and achievement in physics

Our second research question focused on student enrollment and achievement in physics. An examination of enrollment and achievement data in year one indicated promising results, with the year two findings revealing additional progress. Figure 1 illustrates the reduction in the percentage of students not earning credits from baseline through year two. The non-passing rate fell from 3.6% to 1.9%, with the percentage of female students not earning credit dropping below one percent by year two, and the percentage of minority students not earning credit declining from 9% at baseline to 2.6% in year two. An examination of pass rates by gender and minority status indicates that much of this progress was attributable to female minority students, whose non-pass rate declined from 7.9% at baseline to 0.5% at the end of year two (figure 2).

These reductions are even more meaningful when combined with the increases in enrollment. From baseline through year two, we observed an 80% increase in physics enrollment among all students. Female and minority students accounted for much of this, with female enrollment in physics increasing by 211% and minority students experiencing a 308% increase by year two (figure 3). Female minority students represented much of this, with enrollment increases from *n*=127 at baseline to *n*=624 in year two, an increase of 391%. These findings indicate that considerably more underrepresented students were being exposed to rigorous physics content *and* that larger percentages of students were succeeding in the course.

Fig. 1

Percentage of students not earning physics credit

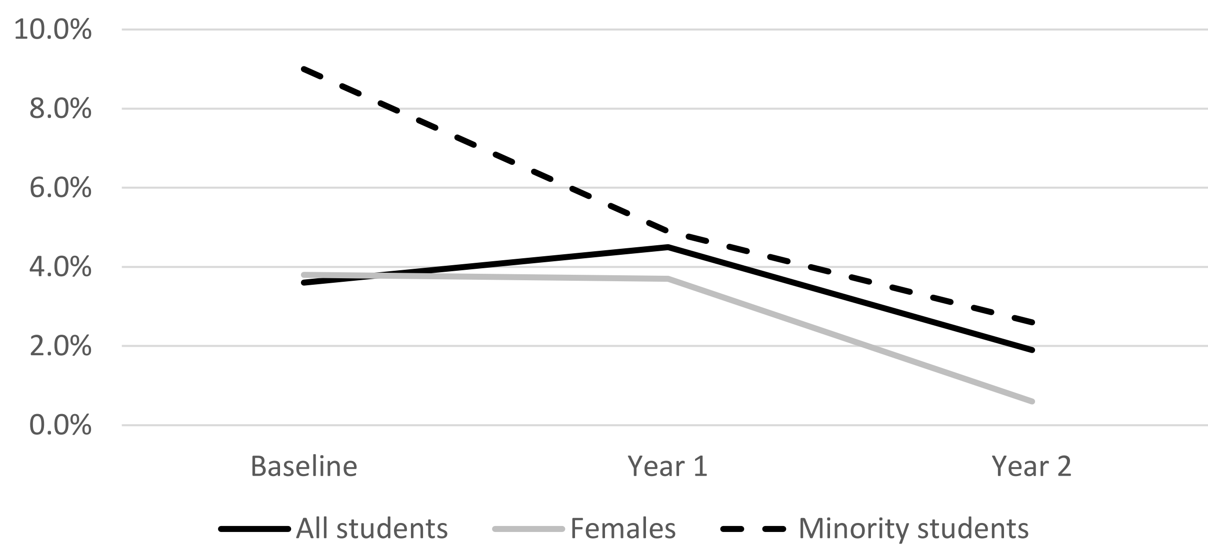


Fig. 2

Percentage of students not earning physics credit by gender and minority status

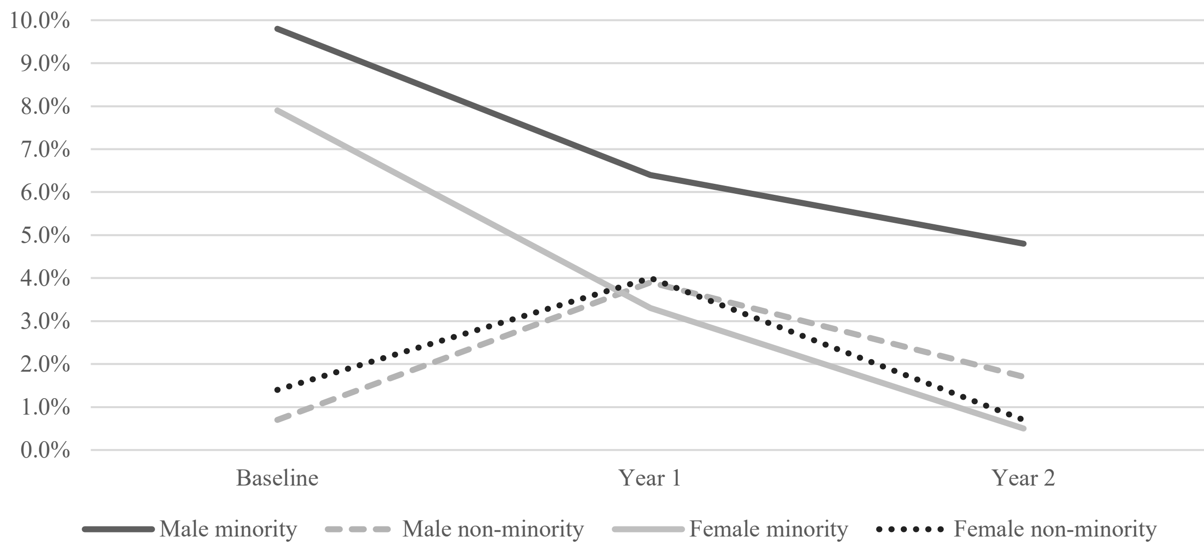
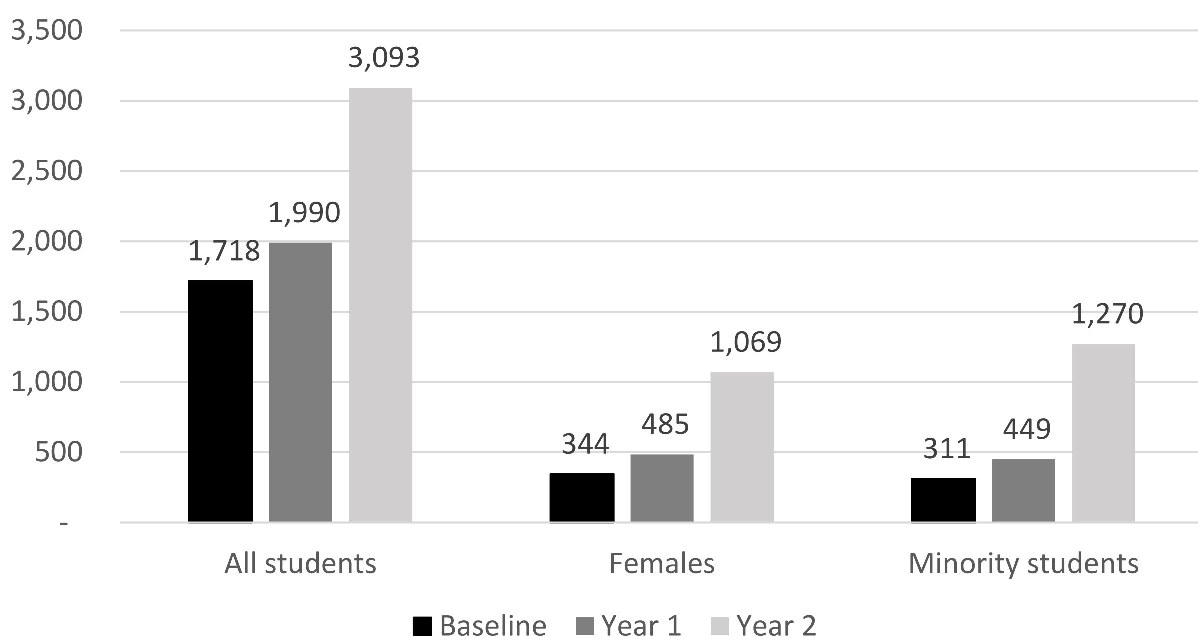


Fig. 3

Student enrollment in physics since introduction of EP curriculum



Factors that may explain student outcomes

To address our third research question, we examined factors related to the EP curriculum and its associated professional development that might influence student outcomes. First, we examined whether teacher perceptions of their physics PCK, use of instructional strategies that promote science teaching and learning, and confidence in teaching physics could impact student outcomes. Responses on the Teacher Questionnaire (pre-PD $n = 41$, end of year two $n = 26$[2]) indicated no significant differences from before training through year two for physics PCK, use of instructional strategies to improve student learning, and overall confidence in teaching physics. We believe this is likely attributable to ceiling effects observed at the initial survey point, where teachers agreed or strongly agreed that they possessed sufficient physics PCK, that they were already using instructional strategies that support higher-order thinking, and that they were confident in their ability to teach physics (see table 4).

Table 4

Comparison of teacher responses on survey subscales from pre-training to end of year 2

Teacher Survey Subscale	Pre-PD *m (SD)*	End of Yr 2 *m (SD)*	*t*	*df*	*p*
Physics PCK	21.7 (2.7)	21.1 (2.7)	0.91	62	.37
Instructional strategies that support physics teaching and learning	33.1 (5.1)	33.4 (2.8)	-.42	65	.67
Confidence in ability to teach physics	35.1 (3.2)	35.5 (4.4)	-.35	65	.73

However, most teachers who responded at the end of year two (88.5%) indicated that their students were more engaged with their classwork when using the EP curriculum compared to their previous physics curriculum and that the curricular resources provide students with the help they need in the areas where they struggle the most with physics (57.7%). Teachers also felt that EP increased their students' learning (88.5%). Further, teachers indicated that their students were better prepared to take tests because of the EP curriculum (70%).

[2] Teacher questionnaires in year two were collected after school closed due to the COVID-19 pandemic, which may explain the low response rate that year.

In their open-ended responses, teachers identified EP laboratory equipment and accompanying investigations as beneficial factors. Teachers explained that the curriculum was advantageous because the "lab equipment facilitates inquiry," and that the resources allow for "exploration with minimal information" provided. One teacher noted that "the simulations allow for students to observe and experience in real time without the time to set up, design, and conduct an experiment," adding that they are now able to explore "simulations that we could never accomplish in a high school physics class" until now. Teachers found these resources to be adaptable and integrated, promoting easier understanding of physics concepts among students.

Findings from the teacher interviews expanded on these factors, with teachers noting that EP had an impact on their instructional practices through the curricular materials, lab equipment and resources that were available for use in the classroom. Digital resources and content were mentioned multiple times by respondents and were described as useful. Three teachers stated that the textbook presented content in a way that makes it easy for students to make connections with physics concepts. Teachers found these curricular components to be beneficial tools, noting that the incorporation of the lab equipment in their classrooms increased hands-on participation among students. One participant stated, "I have the equipment now for every student to participate in the labs. Before, I had to demo the experiment and then have the students work through the labs in larger groups, but we often didn't have time for everyone to participate." Other teachers mentioned that the labs and equipment were designed to work together, which was helpful. One teacher stated that "it's so nice to be able to conduct an experiment that results in accurate, reliable data. The EP equipment minimizes inaccuracies, which is essential." Other teachers increased the frequency of labs in their classroom as a result of its ease and accessibility.

During the interviews, teachers were asked to discuss other EP program factors that may have impacted their students. Participants noted positive changes in their students as a result of the implementation of the curriculum. Common themes revealed that students adjusted well to the curriculum, gained confidence, gained hands-on knowledge, and grew interest in STEM. Teacher comments about the curriculum included, "Essential Physics is user-friendly, it does not scare the students," "My students have become more comfortable trying and sharing ideas," and "The hands-on, practical nature of the curriculum helps students learn." Several participating schools offered "flex" periods during the school day. During these sessions, students who were considering enrolling in physics[3] were able to explore physics concepts through equipment such as the Rocket Launcher and observe demonstrations of experiments by current students. We believe these experiences combined with the success of their peers in physics likely contributed to increases in interest and enrollment in physics.

Finally, teachers described how connections made between physics content and STEM careers may have positively influenced student STEM-career interest and enrollment in physics. Some teachers relied on their personal experience or experiences of friends or family members who serve in STEM careers to offer insight into these fields while others encouraged students to explore STEM careers through periodicals (print or online) such as magazine articles that focus on applications of physics in careers and life in general. One teacher noted that EP digital content included information that helped students connect course content with STEM and engineering careers. Each respondent noted that he or she often makes these connections whenever the opportunity arises, with one commenting that "everything we do, I try to connect to real life."

Discussion

Whereas successful completion of high school physics courses is associated with matriculation into a STEM major in college (Redmond-Sanogo et al., 2016), low rates of physics achievement by female and minority students represent a narrowing of the STEM pipeline at the pre-college level. In this study, we examined trends in student achievement and STEM career interests following the adoption of the EP program, which emphasizes hands-on learning and the application of physics and mathematics concepts to real world scenarios. Including a baseline year, data were collected over a three-year period from more than 40 high schools that demonstrated improvements in students' STEM career motivation, course enrollment, and course completion, with particular benefits for historically underrepresented groups of students. This finding is notable given that most of the participating schools had large numbers of economically disadvantaged students, which is a known risk factor for attrition from high school physics courses (White & Tesfaye, 2011).

Our data revealed that students' interest in STEM careers was either stable or increased over time. This finding is encouraging, as other researchers have highlighted the importance, and the fragility, of early high school STEM career interest. In their large-scale, retrospective study of more than 6,000 college students, Sadler et al. (2011) found that STEM career intentions

[3] In participating schools, physics is a self-selected course; completion is not a requirement of graduation.

declined more sharply among females than males, and that a decline in STEM career interest during the early portion of high school was particularly influential. Notably, those interested in physics related careers at the beginning of high school had the highest retention rates in STEM at the undergraduate level. Further research is needed to examine the longitudinal impact of completing the EP course, but given that Sadler and colleagues found that the strongest predictor of career intentions upon graduation from high school was students' initial high school career interests, our accumulated data provide grounds for cautious optimism toward the effect of the course on students' attitudes regarding STEM careers.

Unsurprisingly, subgroup differences in STEM related course enrollment are a major sustaining cause of disparities in STEM career participation (Isaacs, 2000; Sadler et al., 2011; Wang & Degol, 2017). Trends in robust enrollment for STEM courses by females and minorities at the high school level tend to reflect interest in biological rather than physical science courses, yet our findings revealed an increase in enrollment in physics across multiple years of the project. What was particularly encouraging was that increasing enrollment was also accompanied by a decrease in the percentage of students who did not achieve course credit. This trend appeared for female and minority students, who have been identified as being at risk of attrition from physical science courses in studies where patterns of enrollment and achievement in high school and college settings have been examined (Hazari et al., 2007; Swail et al., 2003). This may have been because females and minorities found physics content to be more accessible (Carlone, 2003) through the EP curriculum due to its hands-on nature, promoting both enrollment and achievement (Beckett et al., 2016). Future research might investigate whether female and minority students find that this approach helps them recognize that physics aptitude is progressive and can be developed over time and experience rather than remaining a fixed or innate ability (Heyman et al., 2002).

Through surveys and interviews, teachers in this study revealed their impressions of the factors that may have contributed to increases in overall and subgroup student achievement and interest in STEM. Thematically, these findings fell into two categories: teachers' perceptions of the instructional resources, and teachers' perceptions of students' responses to the instruction. Teachers recognized the benefits of having equipment that could be used to conduct specific experiments or demonstrations, but more than half of the teachers also felt that the type of support the resources provided was helpful for specific, challenging areas of the curriculum.

Between 70% and 90% of the responding teachers felt that the program increased student learning and their preparedness for assessments, suggesting that overall teachers were satisfied with the academic rigor and quality of the program's components. Teachers also gave favorable impressions of the way these resources were implemented during instruction; and reported that students were more engaged with coursework and had opportunities to explore career related connections and applications of the content. Although not causal, these findings point to the possibility that in addition to students' academic learning, their interest in the subject matter and its applications may have been improved. This finding is in agreement with broader literature on physics education specifically, as studies have noted the role of both concept- and application-driven interest in the development of intentions to persist in STEM (Juuti et al., 2009; Rainey et al., 2018; Singer et al., 2020). Future research is needed to understand the interplay among conceptual learning, sustained personal interest, and career related interest in physics, but our findings suggest that these and other factors that may influence STEM persistence can be primed through the implementation of an introductory course in high school physics.

Limitations

The study has several noteworthy limitations. First, due to its naturalistic design in which the researchers followed the implementation of a program that school districts had elected to adopt, our study was unable to compare the program to a business-as-usual group. Second, longitudinal data on students' subsequent science and mathematics course enrollment were not available for this study, so we are unable to conclude whether participation in EP had long term impacts on students' engagement in the STEM pipeline. Third, since no standardized assessment exists for physics in the participating schools' state, we were unable to verify the nature of students' learning gains for particular physics and mathematics-related concepts and skills. Finally, the available resources for this study did not permit direct observation of classroom teaching before or during implementation. We are hopeful that all of these limitations will be addressed through future research to provide additional insights into the nature of students' learning and career related interest as a result of studying introductory high school physics, and the role that these experiences play in maintaining participation in the STEM pipeline.

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