Priming the STEM Pipeline through High School Physics

Shanan Chappell Moots, Ph.D.
Research Associate Professor & Director of Research Analytics
Joanna K. Garner, Ph.D.
Executive Director & Research Associate Professor
Melani Loney
Program Manager, STEM Education Initiatives
Halldora Webster
Director of Business Operations

The Center for Educational Partnerships
Old Dominion University

Please direct correspondence to:

Shanan Chappell Moots, Ph.D.
The Center for Educational Partnerships
Old Dominion University
4111 Monarch Way, Suite 406
Norfolk, Virginia 23508
757.683.6957 ▪ schappel@odu.edu

Priming the STEM Pipeline through High School Physics

Abstract

Student participation in 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 racial-ethnic minorities. This study examines outcomes from the implementation of an evidence-based participatory curriculum which included access to physics resources and comprehensive teacher professional development. Findings revealed positive impacts on students' interest and achievement in physics, particularly for females and minorities. Despite strong student outcomes, teachers' perceptions of their efficacy to teach was negatively impacted by the shift to virtual instruction associated with COVID-19. We conclude by briefly describing steps being taken to respond to and evaluate this need.

Priming the STEM Pipeline through High School Physics

Physics, chemistry, and algebra are gatekeeper courses to technical careers in any engineering or technology discipline. In order to increase the number and diversity of students who choose careers in science, technology, engineering, and mathematics (STEM) fields, high schools need to increase participation, achievement, and teacher capacity. One way to do this is to improve the curriculum so that it reaches all students and allows educators to enable long-term instructional change. The goal of such a curriculum would be to have all students understand physics and engineering enough to generalize their experiences to new situations. Achieving this goal requires instructional practices that advocate active, participatory learning rather than traditional passive methods of teaching and learning (Scarlatos & Scarlatos, 2008; Arner, 1998).

The researchers and educators involved in this project posit that classroom practice can be revised through the use of engaging, hands-on techniques supported by instructional resources and teacher training that can merge practical interactivity and traditional science in a manner that meets curricular standards. This approach should combine physical and online equipment and resources, participatory, inquiry-oriented curricula, and teacher professional development (PD) which is aligned with Next Generation Science Standards (NGSS) and applicable state standards. Training and implementation of the curriculum should emphasize the development of enhanced pedagogical content knowledge (PCK) in participating teachers, and prepare them to increase the use of challenging, inquiry-based instructional strategies.

Purpose of the study

The purpose of this study was to examine how the Essential Physics (EP) curriculum (Hsu, 2017) influences student interest in STEM careers, enrollment in high school physics, and achievement in physics, particularly among female and minority students. To investigate both teaching and learning in physics, we also assessed how the curriculum affected participating teachers' physics PCK, their use of instructional strategies to support learning, and to foster confidence for teaching physics, as well as how these factors were affected by the school closures due to COVID-19. We addressed the following research questions: 1) How does the EP curriculum influence teachers' PCK, use of instructional strategies to support physics learning, and confidence for teaching physics? 2) How were these teacher factors affected by the school closures during COVID-19; 3) How does the EP curriculum influence student interest in STEM careers; 4) How does the EP curriculum influence student enrollment and achievement in physics?

Theoretical Framework

A competitive US workforce requires students who are interested in obtaining undergraduate degrees in STEM subjects. However, many undergraduate students are not interested in pursuing STEM majors in college. One predictor of entry into a STEM major is a student's interest and participation in higher level mathematics and science in high school (Saw, Chang & Chan, 2018). Various studies have indicated that the level of mathematics and science that students participate in during high school has an impact on the selection of a STEM major in college (Chen & Weko, 2009; Crisp & Taggart, 2009; Tyson, Lee, Borman, & Hanson, 2007).

The number of students choosing to take high school physics remains low (DeWitt, Archer, & Moote, 2019). Traditionally, females and minority students have been less likely to pursue degrees in STEM subjects than white males (Saw et al, 2018). This may be due to the reluctance of female and minority students to participate in the upper level science courses such as physics in high school. While some female students do participate in upper level high school science courses, the courses tend to be in the biological sciences and not physics. Minority students, on the other hand, tend not to participate in the upper level courses at all (Tyson et al, 2007). In recent years, female and minority students have made strides toward closing the physics attainment gap with the advent of specialized high school academies. However, in general education high schools, the same opportunities for success may not be readily available (Conger, Long, & Iatarola, 2009). Providing female and minority students with an engaging physics program that provides a practical application of scientific concepts may increase the overall participation of both underrepresented groups in high school.

The 21st century skills of communication, problem solving, and critical thinking are essential components in educating students to become citizens who are prepared to contribute to society. High school courses that foster these skills benefit students throughout college and into the workplace (Carlgren, 2013). Juuti and Lavonen (2016) found that pedagogical practices such as scientific investigation and the social construction of knowledge influenced student interest in pursuing physics and enabled student success during the completion of physics coursework.

The EP program provides students in general education high schools and specialized academies with an avenue to success through a physics curriculum grounded in 21st century skills. Through the implementation of pedagogical practices that foster student interest and success, the EP curriculum may be one avenue to fostering interest and appreciation of STEM subjects in high school and beyond.[1]

Methods

This study took place at the conclusion of the second year of EP implementation. We employed a mixed-method design (Leedy & Ormrod, 2010), using quantitative techniques to investigate teacher outcomes to measure physics PCK, use of instructional strategies to advance

[1] In the full conference paper, we will provide examples of lessons and activities.

physics learning, and confidence in teaching physics. We also employed a quantitative, within-group design to examine changes in student interest in STEM careers and enrollment and achievement. We applied qualitative techniques to analyze responses to open-ended survey items on the teacher questionnaire to help explain the changes observed.

Data for this study are drawn from 46 high schools in ten school districts across one mid-Atlantic state. Participating schools typically have only one physics teacher who offers several sections of physics each year. Data from the 2017-2018 school year served as a baseline measure for student outcomes, with the 2018-2019 school year being year one and 2019-2020 being year two. In year one, the project served 1,990 students, 41% of whom identified as female and 38% of whom identified as non-white minority. In year two, the project expanded to serve 3,093 students, with subgroup enrollment increases observed for female (45%) and minority (54%) students.

Data sources

We administered a Teacher Questionnaire to measure teachers' perceptions of their physics PCK, instructional strategies, and confidence in teaching physics. We also asked teachers to identify the most successful components of the curriculum. Questionnaires were administered before the PD was offered and again at the end of year two. To assess the impact of school closures that occurred during the COVID-19 pandemic on physics teaching and learning, we included items on the end-of-year survey to reflect teachers' experiences and confidence in teaching during the shutdown.

To measure student interest in STEM careers, we administered the STEM Career Interest Survey (STEM-CIS; Kier, Blanchard, Osborne, and Albert, 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 fields. The STEM-CIS can be administered in a pre/post manner to examine change over time. Participating students complete the STEM-CIS before and after taking physics to examine program impacts on students' interest in STEM career paths.

Participating schools provided enrollment, demographic and achievement data for all participating teachers' physics courses. Final course grades served as our measure of achievement as the participating school districts no longer administer a standardized, end of course assessment for physics. Data from the 2017-2018 school year were collected to establish a baseline for comparison. 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, students do not receive credit for the course.[2]

Results

Responses on the Teacher Questionnaire indicated no significant differences from before training until March of 2020 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 one).

A majority of teachers (88.5%) indicated that their students are more engaged with their classwork when using the EP curriculum and that the curricular resources provide students with

[2] In the full conference paper, we will include the instruments used to assess the impact on the teachers and students.

the help they need in the areas where they struggle the most with physics (57.7%). Teachers also responded that EP increased their students' learning (88.5%). Teachers explained that the EP curriculum was advantageous because the "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 the resources to be adaptable and integrated, promoting easier understanding of physics concepts among students.

However, when asked about their experiences teaching physics during the COVID-19 school closures, we observed statistically significant decreases for the instructional strategies and confidence in teaching physics subscales. Interestingly, the composite score for physics PCK increased during the COVID-19 shutdown. Clearly, teachers were confident in their physics PCK but were lacking in instructional strategies and confidence for sharing this knowledge with their students in a distance learning environment (see table two).

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 (table one). 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 (see table two).

An examination of enrollment and achievement data in year one indicated promising results, with the year two findings revealing exceptional 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. 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 2). These findings indicate that considerably more underrepresented students were being exposed to rigorous physics content *and* that larger percentages were succeeding in the challenging course.

Scholarly Significance of the Work

This study describes the results of a multi-district, regional effort to increase teacher knowledge and student participation in physics. The curriculum and its associated PD improved student outcomes, particularly for historically underrepresented students. Despite unprecedented interruptions due to COVID-19, overall pass rates remained strong. However, our findings indicated an emerging need for teacher support once schools shifted to a virtual instruction model. This need is currently being addressed through an enhanced focus on strategies for teaching physics in a distance format, and plans are being made to trace the impact of the shift on teachers and students during the upcoming school year.

References

Arner, B. (1998). One teacher's perspective: Simulation in the classroom. *Science Activities, 35*(1), 3-4.

Carlgren, T. (2013). Communication, critical thinking, problem solving: A suggested course for all high school students in the 21st century. *Interchange*, 44, 63-81.

Chen, X, & Weko, T. (2009). *Students who study science, technology, engineering and mathematics (STEM) in postsecondary education.* Stats in brief. Washington, D.C: U.S. Department of Education.

Conger, D., Long M.C., & Iatarola, P. (2009). Explaining race, poverty, and gender disparities in advanced course taking. *Journal of Policy Analysis and Management, 28*(4), 555-576.

Crisp, N.A., & Taggart, A. (2009). Student characteristics, per-college, college, and environmental factors as predictors of majoring and earning a STEM degree: An analysis of students attending a Hispanic serving institution. *American Educational Research Journal*, 46(4), 924-942.

DeWitt, J., Archer, L., & Moote, J. (2019). 15/16- Year-old students' reasons for choosing and not choosing physics at a level. *International Journal of Science and Mathematics Education,* 17, 1071-1087.

Hsu, T. (2017). *Essential Physics* (3rd ed.). Roseville, CA: PASCO.

Juuti, K. & Lavonen, J. (2016). How teaching practices are connected to student intention to enroll in upper secondary school physics courses. *Research in Science and Technological Education*, 34(2), 204-218.

Kier, M., Blanchard, M., Osborne, J. & Albert, J. (2014). The development of the STEM Career Interest Survey (STEM-CIS). *Research in Science Education, 44, pp.*

461-481.

Leedy, P. & Ormrod, J. (2010). *Practical research: Planning and design* (9th ed.). Upper Saddle River, NJ: Pearson Education.

Saw, G., Chang, C.N., & Chan, H.Y. (2018). Cross-sectional and longitudinal disparities in STEM career aspirations at the intersection of gender, race/ethnicity, and socioeconomic status. *Educational Researcher.* Advance online publication. Doi10.3102/0013189X18787818.

Scarlatos, L. & Scarlatos, T. (2008). Teacher directed active learning games. *Journal of Educational Technology Systems, 37*(1), 3-18.

Tyson, W., Lee, R., Borman, K.A. & Hanson, M.A. (2007). Science, technology, engineering, and mathematics (STEM) pathways: High school science and math coursework and postsecondary degree attainment. *Journal of Education for Students Placed At Risk, 12*(3), 243-270, DOI: 10.1080/10824660701601266

Table 1

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

Table 2

Comparison of teacher responses on survey subscale before and after school closures due to COVID-19 pandemic

Teacher Survey Subscale	Pre-COVID *m (SD)*	During COVID *m (SD)*	*t*	*df*	*p*
Physics PCK	11.8 (1.8)	16.1 (3.1)	8.00	25	<.001
Instructional strategies that support physics teaching and learning	16.4 (1.9)	12.4 (4.6)	5.70	25	<.001
Confidence in ability to teach physics	26.8 (3.3)	16.1 (3.1)	6.01	23	<.001

Table 3

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
Students of color	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
Students of color	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 4

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 students	0.3	1.27	3.57	3.92	5.71	6.53	1.32	1.39
Non-minority vs students of color	1.36	0.88	0.75	0.31	2.62	0.04	1.62	0.13
Year Two								
Male vs female students	0.33	-1.53	3.47	2.44	5.93	5.66	1.09	3.52
Non-minority vs students of color	1.51	1.72	0.72	-0.34	-0.67	-0.04	0.58	0.51

Figure 1

Percentage of students not earning physics credit

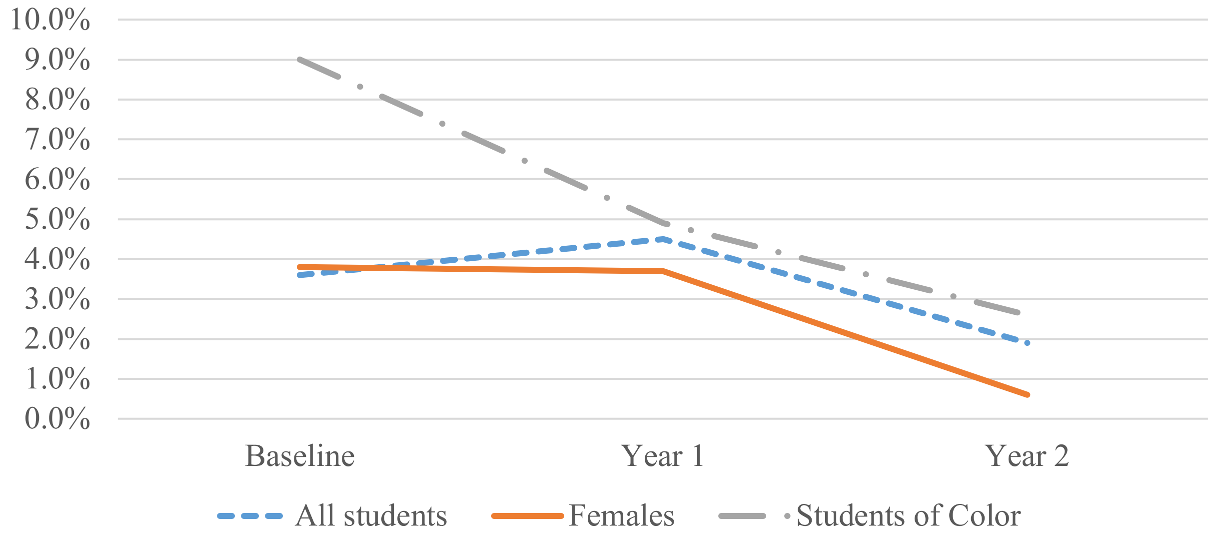

Figure 2

Student enrollment in physics since introduction of Essential Physics curriculum