Impact of an Emerging Scholars/Peer-Led Team Learning Program on the Recruitment of Undergraduate Women and Underrepresented Minorities into Computer Science and Mathematics

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Abstract
In 2018 women, Black and Hispanic students accounted for 19.9, 9 and 11%, respectively, of undergraduate degrees in computer science (CS). Black students were awarded 5% of degrees in math and Hispanic students 11% [1]. This project studied the impact of an Emerging Scholars Program, a Peer-Led Team Learning program with the goal of recruiting women and underrepresented minorities into math and CS. A collaboration between the Mathematics and CS Departments was established in 2013 at the University of Pennsylvania. Freshman and sophomores with undeclared majors were actively recruited**.** Workshops led by peer leaders and conducted weekly focused on collaborative problem solving. Program outcomes were assessed quantitatively by the proportion of participants choosing CS or Math programs following project participation, and qualitatively by surveying the impact of the program in participants' own words. 386 students with undeclared majors participated in the Penn Emerging Scholars Program (PESP) between 2013 and 2020, including 52.6% female, and 18.5% Black and Hispanic students. Majors or minors in CS or Mathematics were chosen by 65% of 147 majority males, 77% of 35 minority males, 63% of 166 majority females and 41% of 36 minority females. A larger percentage of underrepresented minority respondents (67%), as compared to all respondents (26%), credited PESP with helping them connect to peers in math classes ($p< 0.001$) and emphasized the importance of those connections in their academic journey. Survey respondents reported that PESP introduced them to new ways of thinking and a variety of areas of CS and math. They formed friendships, benefitted from peer leader mentoring, and became part of a math and CS community. PESP was particularly effective in recruiting minority and female students. Problem solving with peers demonstrated that CS and Math are collaborative activities focusing more on problem solving and algorithmic thinking than programming or solving equations. Program development and processes as well as qualitative and quantitative outcomes are described. Future efforts addressing the needs of minority female students are needed.

Introduction

Postsecondary peer cooperative learning programs have long been used to support student learning in mathematics, the hard sciences and engineering, and in recent years computer science (CS). In 2013 at the University of Pennsylvania, the Mathematics and CS departments established the Penn Emerging Scholars Program (PESP), a Peer-Led Team Learning program (PLTL) with the goal of recruiting women and underrepresented students into math and computer science. PESP used PLTL workshops, in an effort to increase the number of students in Math and CS, by demonstrating that these disciplines are necessarily collaborative activities that focus more on problem solving and algorithmic thinking than on programming or solving equations. For freshmen interested in math and CS but unsure that the disciplines were a fit for them, PESP offered an exciting workshop experience in which they could delve into logical problems which

underlie CS and math theory in a small group setting. The percentage of women undergraduates in the CS major at the university in 2013 was 26%, Black 5% and Hispanic 5%. Our hypothesis was that a non-threatening workshop environment would increase students' comfort level with the academic material, provide an opportunity to get to know peers through an intellectual activity, build students' confidence that they could succeed in mastering concepts through problem solving, and give us an opportunity to provide mentoring. Our team conducted a two-part study to evaluate the impact of PESP on participants' selection of academic programs subsequent to their participation in the workshop program. We examined participants' selection of majors and minors from the program's inception in Fall 2013 to Fall 2020. In addition, the results of a survey, distributed to all PESP students since the program's inception to discern the impact of the program on participants in their own words, provided a second data source for this study. Our specific aim was to recruit PESP students into the math and/or computer science majors and minors.

CS has one of the lowest proportions of female degree recipients among the fields of science and engineering, and nationally women's share of bachelor's degrees in computer science declined from 27% in 1998 to 19.9% in 2018. In mathematics and statistics over the past 2 decades, the percentage of women receiving bachelor's degrees declined and the rate of women receiving master's degrees was stagnant. Black and Hispanic students remain underrepresented among Science and Engineering degree recipients relative to their representation in the overall population (13.6 and 18.9%, respectively). Black students were awarded 9% of the bachelor's degrees in computer science and 5% of the bachelor's degrees in math. Hispanic students earned 11% of the bachelor's degrees in computer science and 11% of the bachelor's degrees in math [1]. Previous work attributes the persistent underrepresentation to a lack of pre-college experiences, lower awareness of opportunities in these fields, and a dearth of role models [2], [3], [4], [5]. The US Bureau of Labor Statistics projects a much higher growth in jobs in computer science, math, and statistics than the 5% median rate for all professions. From 2021 to 2031, jobs for Computer and Data Scientists are projected to grow by 21%, Software Engineers by 25%, and Mathematicians and Statisticians by 31%, along with a median salary over $100,000 for each of these occupations [6], [7]. A large segment of the US population is not benefitting from the opportunities provided by CS and math, and growing a strong and talented science and technology workforce is a key US national goal to maintain global leadership and competitiveness along with investing in research and encouraging innovation [8].

Previous Work

Introductory courses serve as gateways to many majors in science and engineering. A key barrier to success in the STEM curriculum is very high rates of failure or withdrawal in introductory STEM courses. Traditionally the format for instruction is lecture oriented, often in large lecture halls not conducive to student interchange and discussion, so students work in isolation and are unable to engage in course discussion with peers outside of class [2], [5], [9], [10]. Peer Led Team Learning (PLTL) and Emerging Scholars Programs (ESP) offer a small-group discussion approach to support student learning in math, the physical sciences, computer science and

engineering at institutions such as the University of Texas, Austin, University of California, Berkeley, Columbia University, Duke University, University of Wisconsin, The City College of New York and hundreds of other institutions.

ESP and PLTL–Similarities and Differences

The Math Workshop was founded by Uri Treisman at the University of California, Berkeley in 1977 and later renamed the Emerging Scholars Program when Treisman moved to the University of Texas, Austin in 1991. The program's goal was to motivate Black students to persist and succeed in math courses by providing them with an honors workshop adjunct to the first-year calculus course. Treisman found through his research that Black students studied alone and did not benefit from discussing course concepts to reinforce their learning outside of class. The Emerging Scholars Program involved students solving challenging calculus 1 problems in workshops in which trained graduate students facilitated the problem-solving process using Socratic questioning and offering help when necessary. Subsequent research by Treisman indicated that offering freshmen a non-threatening, small-group but challenging environment to explore math concepts impacts participants' success in these subjects and motivates them to persist [10], [11], [12].

Funded by the National Science Foundation, the PLTL model was first developed for General Chemistry at the City College of New York in the early 1990's and later extended to math, biology and engineering courses. The PLTL model has become a nationally recognized and replicated model of STEM education [13], [14]. PLTL and ESP are similar in that students work together in small groups of 8 to 15 on challenging problems under the guidance of trained peer leader facilitators outside of the classroom. PLTL workshops are usually adjunct to a specific course, and the group work centers around course materials. PLTL Peer Leaders are undergraduates who have been previously successful in the course, and who demonstrate superior interpersonal and leadership skills. Peer leaders are trained to facilitate the workshop by presenting the problem and guiding the students to solve it collectively using brainstorming, analysis and discussion.

Active recruiting is a key difference between PLTL and ESP. PLTL does not involve active recruiting since all members of the course are invited to participate in the workshop. ESP is designed for freshmen at risk for attrition because they come from underrepresented groups in the discipline and have not been adequately exposed to these disciplines in high school. Many students are not exposed at all to CS in high school and the introductory CS course is often their first experience with the subject. Large lecture-based classes and complex one-person programming assignments can be daunting to students with no CS experience. However, ESP/PLTL encourages active learning, as opposed to the traditional model of passive listening to lectures in an auditorium filled with hundreds of students [15]. Students are actively recruited for ESP workshops, and group work centers around challenging problems in math or science under the guidance of trained student facilitators, who may be graduate students or upperclassmen undergraduates similar to PLTL. ESP may be adjunct to a particular course but need not be.

In 2004 Horwitz and Rodger documented the success in recruiting women and underrepresented students into CS utilizing active recruiting through an ESP/PLTL program in a multi-year, eight-university study. Their program is described as a combination of ESP and PLTL in that participation in the workshop was voluntary; women and underrepresented students were actively recruited; participants worked on challenging problems in small groups under the guidance of an undergraduate peer leader; and the workshop problems were aligned with topics in an introductory CS course. Extensive evaluation indicated that this program attracted under-represented students who would not have otherwise taken a CS course; participation in the program significantly improved course retention rates and grades, especially for women; and program participants and their peer leaders were enthusiastic about their experience [16].

In 2006, faculty at the University of Washington, Tacoma employed ESP to improve student learning as measured by grades in an Algorithms course and a Data Structures course. Students at this school tend to be non-traditional in that most are transfers from community colleges and do not reside on campus. Therefore they do not have many opportunities to become acquainted with peers and work in informal study groups. ESP workshops were offered as 2 credit courses separate from the lecture courses and enrollment was voluntary. Evaluation indicated that the method was more successful in improving retention and course grades in the workshop adjunct to Algorithms than to Data Structures. The authors concluded that the workshop format was more conducive to the intellectual content in algorithms [17].

The Columbia Emerging Scholars Program (CESP) has been offered to students in the introductory computer science course (CS1) since 2008 and participation is voluntary, but the workshop problem sets are not directly tied to CS1 course content. Instead CESP aims to demonstrate to students the breadth of CS topics, using fun and interesting group problem-solving activities based on the underlying logic of CS concepts. CESP results indicate that the program has been successful in its goals of increasing retention of students, especially women, measured by the number of students who continue on to CS2, and increasing the number of students, especially women, who major in CS [15].

The benefits of PLTL and ESP in participants' course grades and retention have been extensively documented [17], [18], [19], [20], though no previous paper has cited specific numbers of new majors and minors following the PLTL experience. Arendale published an Annotated Bibliography on a variety of College Cooperative Learning Programs in 2021, including ESP and PLTL programs [21].

Methods

ESP/PLTL at the University of Pennsylvania

Similarities exist between Treisman's students and the women and underrepresented minority students targeted for the Penn Emerging Scholars Program (PESP). Like Treisman's students, women and minority students were underrepresented in Math and CS majors at our university, and we posited that the social implications of their underrepresentation caused many of them to be isolated in their introductory math and CS classes. We wanted to replicate in our version of ESP the challenging academic work and the social, emotional and mentoring support that

Treisman successfully provided for his students. Building communities of students with shared academic interests was a goal in our version of ESP. Another goal was to cast a wide net to recruit students with a diversity of interests in addition to CS and Math, who may be attracted to computing and math for their application in other fields.

PESP used elements of both PLTL and ESP. Two 90-minute workshop groups met once a week for 8 weeks with fifteen students each semester beginning in the Fall of 2013. In the workshops, students collaborated to solve algorithmic/logical problems, without the pressure of exams, assignments, grades or competition. Women comprised 52.6% of PESP participants and 18.5% were underrepresented minorities; 60% were freshmen and 40% sophomores. (All participants identified as either male or female on the application form, which also included a nonbinary option and a prefer-not-to-say option.) The vast majority of the students had not yet declared a major. Occasionally we admitted a Math or CS major to the program for the purpose of retaining that student. PESP strove to offer students, who were already interested in CS and math, a program that would build their confidence that they could be successful beyond the introductory course. A distinguishing feature of PESP is that the program was a collaboration of the Mathematics and Computer Science departments, and the weekly problem sets, which were presented on worksheets, drew from topics in both disciplines. PESP gave the Mathematics and Computer and Information Science departments an opportunity to forge a novel collaboration. Both departments attract students interested in quantitative reasoning, and both are interested in increasing the diversity of their students.

At the University of Pennsylvania, we began the program with the help of Columbia's University CESP, which generously shared with us their problem bank to start up our PESP, while we developed our own bank of workshop problems. Each weekly PESP worksheet featured a different topic. The following four problems, whose ultimate provenance is unknown to the authors, were some of the problems from a worksheet on the pigeonhole principle:

1. Without knowing anybody's birthday except your own, can you guarantee that two people in this room have birthdays in the same month? If there are too few people in the room, then how many would you have needed?
2. Suppose you pick nine points inside an equilateral triangle, no three of them in a line. Prove that three of the points you picked form a triangle with at most 1/4 the area of the original triangle. What about six points?
3. Prove that you can't arrange 100 points inside a 13 ×18 rectangle so that the distance between any two points is at least 2.
4. Prove that if you have 51 integers, you can find a pair of integers a and b so that a^2-b^2 is divisible by 100.

Selection of peer leaders

Undergraduate peer leaders guided the undergraduate participants through the workshop problems. In the first year of PESP, peer leaders were selected by faculty for their strength in Math and CS, and demonstrated exceptional interpersonal skills. In subsequent years, peer

leaders were selected from participants who were also strong students and additionally had completed a PESP workshop, demonstrated leadership and strong interpersonal skills, and had selected a Math, CS or closely-related major following their PESP experience. Peer leaders were trained by PhD students from Math and CS who were part of the PESP team. To prepare the week's problems, a PhD student from each department met weekly with the four peer leaders. The peer leaders were paid at the TA rate of $16 per hour for the workshop and prep time, and the PhD students were granted a $750 stipend each semester for their service.

PESP participant recruiting

We recruited broadly for PESP from the CS Introduction to Programming course, which is designed for students with no previous experience with programming, and the CS Introduction to Programming Languages and Techniques course, for students who had prior experience through an advanced placement high school course in CS or similar experience; from math courses at and slightly above the introductory college level, which are taken by freshmen with aptitude and interest in math; and from student culture organizations throughout campus. Although women and underrepresented minority students were actively recruited, PESP also welcomed males who were not underrepresented. Our intent was to ensure gender and ethnically-balanced workshop populations.

Recruiting messages included the following:

> Are you interested in CS and Math but unsure that they are the right fit for you?
> Are you interested in working with like-minded peers in small groups on interesting problems?
> Then the Penn Emerging Scholars Program (PESP) may be for you!
>
> PESP is an opportunity for students interested in Math and/or CS to work in small groups for 90 minutes a week for 8 weeks during the semester and complete logical and algorithmic problems with peer leaders.
>
> PESP is not for credit and there are no projects, tests, homework or programming. Additionally, we serve food at our workshops every week! The only stipulation is that you must attend every workshop unless you have a great excuse. A limited number of students will be selected for these workshops.

From hundreds of recruiting emails and in-person presentations on PESP by team members and former PESP participants to classes mentioned above, students self-selected to apply to the program, and students admitted to the program tended to have an interest in the workshop subject matter. We received approximately 70 PESP applications each semester, and selected 30 students for two workshops.

At the end of each semester, PESP held a reunion party featuring a family-style dinner to reinforce the community of Math and CS students and faculty. Current and previous PESP students (called PESP alums) were invited to the reunion dinner, along with Math and CS faculty, peer leaders, and PhD mentors, who greatly enriched the PESP community. Each

semester we selected a PESP alum, who had graduated from the university, to talk to the students about her job and career plans at the Reunion party. The Reunion party occasionally featured guests from industry.

In addition to the pay for the peer leaders and PhD stipends, the only other costs involved in running ESP were the light suppers provided to the two workshops (approximately $200 per week) and the cost of the end of semester reunion dinner.

Admissions practices at the University of Pennsylvania

At the University of Pennsylvania, students can begin freshman year with a declared major or they can be undecided, which is called curriculum deferred in Penn Engineering and undeclared in the College of Arts and Sciences. The vast majority of students select a major by the end of sophomore year. Students can earn dual degrees by studying for a major in two schools and fulfilling the requirements of both schools, i.e. The Wharton School, the College of Arts and Sciences, the School of Engineering and Applied Science, and the School of Nursing. Students can also earn double majors within each school, and can submatriculate into a master's program. An exciting option that the University of Pennsylvania provides undergraduates is the ability to earn a second major in CS, housed in the engineering school, along with their first major in the college. Students need only complete the college's degree requirements for their college (first) major and the 12 courses required by the Computer and Information Science department for the second major. The engineering school's technical course requirements are not mandated in the second major program. Bringing students with a diversity of interests into a computational reasoning program allowed PESP to cast a wide net and serve the fields through increasing the diversity of ideas which are often missing.

Data Collection

Our data collection plan included quantitative and qualitative components. The quantitative component was derived from tracking the PESP students' selection of majors and minors and submatriculation into master's programs following their participation in PESP. The qualitative component was derived from a survey sent to all PESP participants. 386 participants were emailed the survey. Of these, 102 students, or 26%, responded.

In the 2021-22 academic year, we emailed all participants a survey with Likert scale and checkbox objective questions as well as open-ended qualitative questions. We contacted both current student participants through email and those who had graduated through engineering alumni lists, still-operable college emails and Linked In. In the survey, we asked about participants' understanding of the Math and CS disciplines, their experience with peers and peer leaders, their sense of belonging to a Math and CS community, and benefits, if any, they perceived that they received from PESP.

Results–new majors and minors in Math and CS

From 2013 through 2020, 386 undergraduates participated in PESP. 52.6% of participants were women, and 18.5% were Black and/or Hispanic students. At the time of this study, 86% of PESP participants had graduated from the university. 50% of these participants graduated from the College, 37% from Penn Engineering, and 13% from The Wharton School. 9% of these graduates earned dual degrees in two schools and were counted in the school of their first degree. No students from the School of Nursing participated in PESP. PESP students who did not maintain enrollment in the university were not included in this study. However, PESP students who changed majors or schools following participation in the program were included.

By reviewing university data on PESP participants' outcomes, we were able to determine the majors, minors, and dual degrees of students who had participated in PESP, including those participants who completed a Math or CS master's program in which they had submatriculated as an undergraduate.

Table 1. Proportions of student groups choosing academic programs in CS and/or mathematics following their ESP experience.

	Majority males	Minority males	Majority females	Minority females
Total PESP participants (n)	148	35	166	37
PESP participants who chose Math/CS program	96 (65%)	27 (77%)	105 (63%)	15 (41%)

Results of math and CS academic program selection are as follows:

- 63%--243 PESP participants selected 335 majors, minors and master's degrees in CS, Math, and/or closely related programs (Statistics, Logic Information & Computation, Mathematical Economics, Actuarial Science, and Computational Biology).
- 46%--177 PESP participants selected 189 majors from the targeted majors: CS (133) and/or Math or closely related majors listed above (56).
- 23 PESP participants sub matriculated in and completed master's degrees in Math or CS.
- PESP students selected 123 minors in targeted programs: 56 minors in Math, 55 in CS and 12 in Statistics.
- 59% of the participating women selected a CS and/or Math program. Women selected 85 majors in Math, CS and related majors listed above; and 64 minors in Math, CS and Statistics.
- 67% of the participating males selected a CS and/or Math program. Men selected 104 majors in Math, CS and related majors listed above; and 59 minors in Math, CS and Statistics.

- 58% of the 72 underrepresented minorities selected 50 CS and/or Math programs. Among these participants there were 32 majors in Math and CS, 15 minors in Math and CS, and three master's degrees in CS.

Survey analysis

55% of the 102 survey respondents indicated that they majored in computer science, math and/or a related major (logic, information & computation, mathematical economics and computational biology). 38% of respondents indicated that they had minored in one or more of these disciplines. Of those respondents who had earned a minor, 63% minored in Math, CS and/or a related discipline. Some respondents indicated that they had earned two or more minors in targeted programs. 11% of respondents had earned a Masters in Math, CS or a related discipline.

Analysis of survey questions yielded the following results:

Respondents were given a checkbox question with a list of statements, and asked to check all that apply:

Question: What did you think of your PESP experience? Check all that apply.

Responses: The following are the 5 most endorsed statements out of 16 statements. The statements that were endorsed by the 102 respondents are reflected in percentages of respondents below.

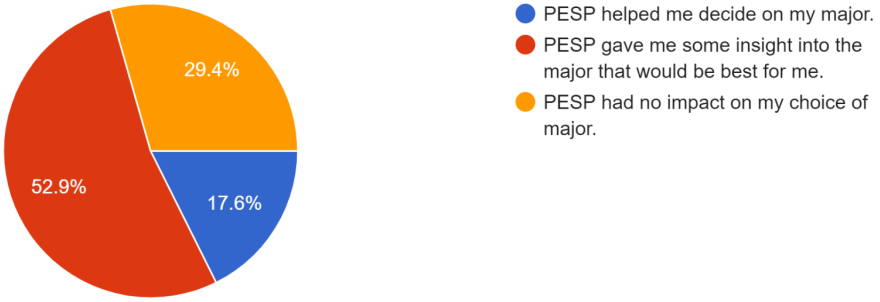
1. PESP was fun–selected by 84% of respondents
2. PESP gave me insight into the types of problems that Computer Scientists solve–selected by 78% of respondents
3. PESP gave me insight into the types of problems that Mathematicians solve–selected by 64% of respondents
4. I made friends!–selected by 48% of respondents
5. PESP helped me connect with like-minded peers–selected by 41% of respondents

The remaining statement options were: I felt like I was part of a community; PESP helped me to decide on a major; I didn't get anything out of PESP; I did not attend many PESP workshops; I enjoyed talking to faculty and other math and CS students at reunion parties; I found that math was for me; I found that CS was for me; I found that math was not for me; I found that CS was not for me.

Respondents were asked the following questions:

12. What impact did PESP have on your choice of major?

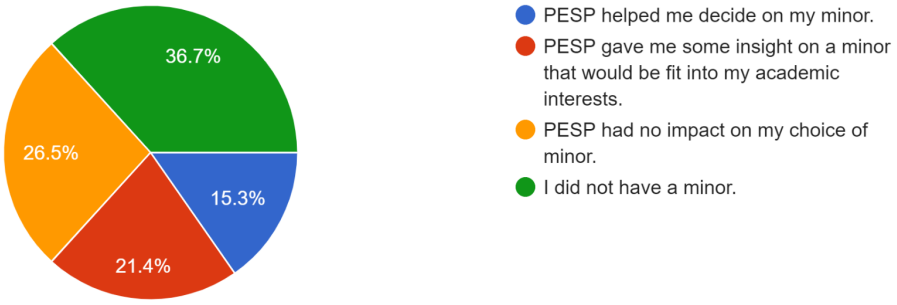
102 responses



70.5% of respondents indicated that PESP either helped decide or gave insight into the respondent's choice of major.

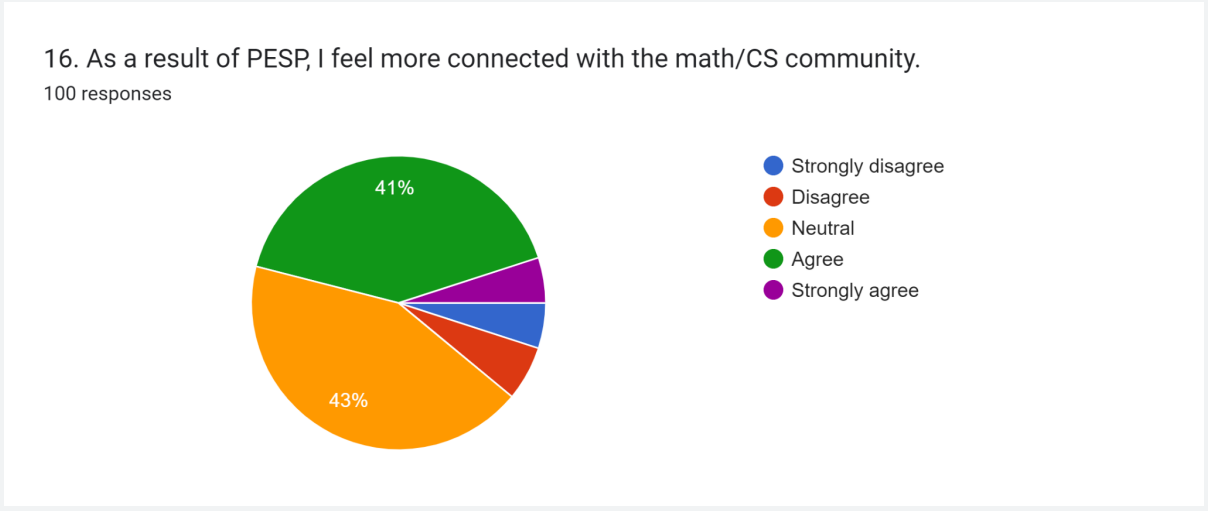
13. What impact did PESP have on your choice of minor?

98 responses

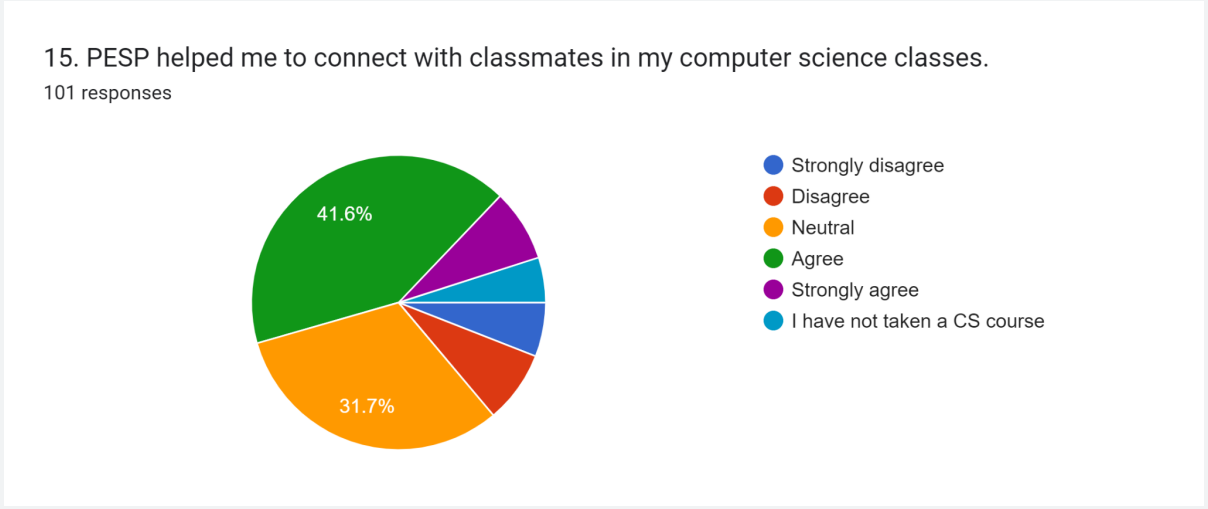


37% of respondents indicated that PESP either helped decide or gave insight into the respondent's choice of minor.

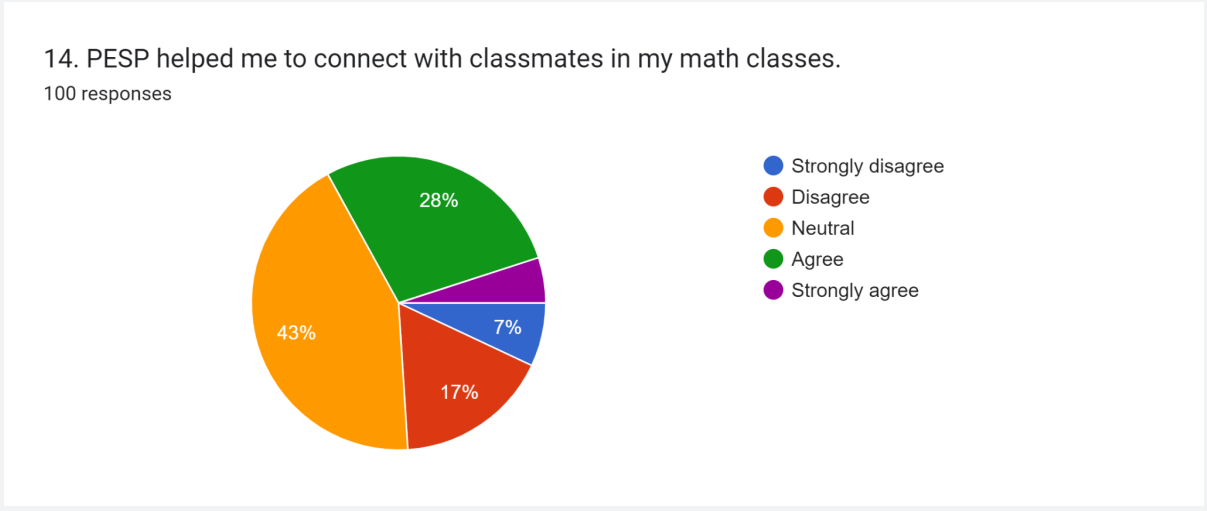
In a 5 point Likert scale, with responses ranging from Strongly Agree to Strongly Disagree, participants were asked the following questions.



46% of respondents agreed or strongly agreed that PESP connected them with the math/CS community. Only 11% disagreed or strongly disagreed with this statement.



49.5% of respondents agreed or strongly agreed that PESP helped connect them with classmates in their computer science classes. Only 13.8% disagreed or strongly disagreed with this statement.



33% of respondents agreed or strongly agreed that PESP helped connect them with classmates in their math classes. Only 24% disagreed or strongly disagreed with this statement.

Open-ended qualitative questions probed for more detail on survey questions and were coded for themes. Respondents gave a total of 116 comments to two open-ended questions.

Question: Describe any effect PESP had on your thinking or your plans following the program.

Question: Describe any thoughts about PESP that have remained with you and perhaps have influenced your plans following graduation from the university.

Following are themes drawn from respondents' answers to the above questions and the number of times each theme occurred in the responses.

PESP built my confidence and interest in technology, STEM, math/CS.--23 students

I valued the friendships I made, and/or the community and mentorship in PESP.--20 students

PESP helped me decide to major in computer science/math.--16 students

PESP was fun. Problem-solving was fun.--15 students

I learned a new way of thinking and a new approach to problem solving in PESP.--12 students

I appreciated the small group environment and collaborative spirit in our problem solving.--8 students

PESP introduced me to concepts and different areas of math/CS.--7 students

PESP helped me realize that math/CS was not for me, but helped me find my interest in another discipline.--5 students

PESP motivated me to take computer science classes.--4 students

PESP Reunion dinners were a good way to keep in touch with people and talk to faculty.--3 responses

Introduction to problem solving and algorithmic thinking in math and computer science early in students' academic career had a significant impact on many participants. A sample of participants' comments from the survey underscores the impact of the program on students in their own words.

> "PESP was a big part of the reason I first considered computer science as a possible major. The program encouraged me to explore the field, introduced me to a diverse range of interesting problems, and anchored me in the department with a community of friends and mentors. PESP is one of the reasons I'm an engineer today."
>
> "I think PESP influenced me in two main ways: 1. I made friends who ended up being in my intro CS courses, which made those courses more fun. 2. More significantly, when I was a beginning CS student and considering minoring in CS, PESP helped me identify as connected to CS."
>
> "I enjoyed the sense of community and shared goal, especially early on in my college experience when I wasn't as sure of my major as I am now."
>
> "Mentorship was huge. Connecting with people and being able to network. I am now heavily involved in mentorship and keep in contact with many folks from PESP."
>
> "PESP made me interested in pursuing further graduate studies in Math/CS, which led me to pursue the Accelerated Masters' in Data Science program as the program combined my interests in computer science and math. I am grateful to have the opportunity to be a participant in PESP and be introduced to different areas of math/CS."
>
> "I was a pre-med in the College of Arts and Sciences my freshman year but after PESP I transferred to the engineering school and pursued engineering. Without transferring, I would not have been able to enter a PhD program and realize that math is what I wanted to do for the rest of my life."
>
> "After being introduced to different problems in discrete math / computer science through PESP, I became interested in pursuing further studies in theoretical computer science, which led me to eventually declare Math & CS as my majors."

> "Making community in the CS/math space helped me feel confident enough to pursue CS."

> "PESP encouraged me that math was a discipline I was capable of pursuing."

> "I made my best friend for life in PESP and I'm forever grateful for that."

Peer leaders were also impacted by the experience leading PESP workshops, as described by one peer leader below.

> "PESP had a strong impact on my college experience in the computer science department, from both an academic and social perspective. I gained so much from it as a freshman that I asked to be a peer leader for the program during my remaining years at the University so I could try to pass along that experience to others."

Discussion

PESP at the University of Pennsylvania benefited from the implementation and results of a few ESP-PLTL programs in other universities. Horwitz and Rodger described the implementation and evaluation of an eight university ESP-PLTL study over three years funded by the NSF and coordinated by the University of Wisconsin-Madison's (UW-Madison) Learning through Evaluation, Adaptation, and Dissemination Center [15]. There are some noteworthy differences between their ESP-PLTL programs and our PESP. Unlike our PESP, the UW-Madison programs were adjunct to the CS1 course and problem sets were tied to the CS1 course content, while our workshop content was not tied to any specific course, but utilized algorithmic, logical problems to demonstrate the depth and breadth of CS and math. Student participation in UW-Madison's program required students to be enrolled in the CS1 course. Our PESP cast a wide net admitting freshmen and sophomores through recruiting in targeted math and CS courses and student culture organizations in keeping with our goal of exposing students, interested in math and CS but unsure if the disciplines were a good fit for them, to the logical problem solving methods of these disciplines in a small group, collaborative environment. UW-Madison compared their ESP-PLTL CS1 results in terms of student grades and retention in the CS1 course with their control group, CS1 results without ESP-PLTL and demonstrated that combining ESP-PLTL with the CS1 course attracted female students who would not otherwise have taken a CS course, increased retention rates for all students in the program, and increased final grades for all students, especially for women. Our PESP study concentrated on tracking participants' major and minor selections following their participation in PESP. We also incorporated an additional component not found in the UW-Madison programs of developing a community of students interested in math and CS through a Reunion dinner at the end of each semester.

The first author of this paper worked with the Columbia University CESP team while serving as an Extension Services Consultant with the National Center for Women & IT [15]. While the CESP paper focuses on how to start up an Emerging Scholars Program, the team's evaluation indicated that after 6 iterations of the program from Spring 2008 through Fall 2010, 45% of CESP students who had declared a major had chosen Computer Science and women's percentage of computer science majors at Columbia increased from 9% in 2007 to 21% in 2010. Similar to CESP at Columbia University, another distinguishing factor of PESP at our university is that the program did not support any specific course material. We were very intentional in avoiding material that duplicated what students might already see in introductory CS and Math courses. Also like the Columbia program, our problem sets avoided computing and calculation to focus on algorithmic and logical ideas which the participating students often did not realize were more typical of advanced courses in these disciplines. However CESP recruited students into their program only from the CS1 course and the program was focused solely in the computer science department, while our PESP recruited students widely throughout the university from math courses and student culture groups as well as from Introduction to Computing courses.

The summative evaluation of the Penn Emerging Scholars Program indicates that PESP successfully attracted students to math and computer science programs. The percentage of women in the computer science major at Penn increased from 26% at the program's inception in Fall 2013 to 36% in Fall 2020, and PESP contributed to the increase in women CS majors with PESP women averaging 11 new majors and 8 new minors per year to the Mathematics and Computer Science departments during the program's 7.5-year duration. PESP effectively leveled the playing field for participants, with women in the program selecting majors and minors in Math and CS at a rate that closely matched men's selection. Noteworthy is the higher rate of selection of Math and CS programs by minority males than majority males. This may have been the result of the peer networking that PESP provided these students. In the follow-up survey, a significantly larger percentage of underrepresented minority respondents (67%), as compared to all respondents (26%), credited PESP with helping them connect to peers in their math classes ($p < 0.001$). The follow-up survey, administered to all past PESP participants, gave detail on the program's impact in terms of connecting peers interested in math and computer science, bolstering participants' confidence that they could be successful in these academic programs, giving them access to a math and CS community, and insight into logical, algorithmic problem solving.

The fact that more than half of the participants were non-engineering students indicates the reach of PESP to students who were not seeking a traditional engineering degree, but were attracted to CS and Math in addition to their other academic interests.

PESP also positively impacted the undergraduate peer leaders and PhD students who supported the program by providing them with a mentorship model, and instilling in them the value of mentorship, and the desire and confidence to be a mentor. Every participating PhD student made

a unique contribution to the program, and the program positively influenced their attitudes toward teaching. The third author of this paper helped to establish the Northwestern Emerging Scholars Program as a postdoc after participating in PESP as a Math PhD mentor. Another Math PhD mentor went on to earn a master's degree in Computer Science at the university in addition to his Math PhD.

The study had a few noteworthy strengths. Collaborations between Math and CS in one program gave synergy to our shared goals. By targeting recruitment to all students enrolled in introductory CS and targeted Math courses, the program invited students with a wide variety of academic interests and focused on students most likely to benefit from the study program. The flexibility provided by the university for students to pursue their interest in science and math through a plethora of programs across all four undergraduate schools made CS and Math attainable to many students.

This study also had a few limitations. The University could not provide numbers of schoolwide students entering the targeted disciplines, so comparison of PESP student outcomes with those of the university at large was not possible. However, students' enrollment in courses targeted for recruitment into PESP, such as Introduction to Computer Programming, does not indicate that these students were likely bound for the CS major. Introduction to Computer Programming is a required course for many engineering majors at the university study site and it is taken by a variety of students, including upperclass students who have already selected a major. The course also fulfills a quantitative reasoning requirement for many majors in the university, which makes it popular with some students. Introduction to Computer Programming is designed for students with no prior background in computing or experience in computer programming, enrolls over 800 students each year with 40% women, and is taken by students in all four undergraduate schools at the university study site. Less than 10% of students enrolled in this course declare the computer science major each year, yet approximately 34% of PESP participants declared a computer science major each year of the program's duration. Likewise students enrolled in targeted PESP recruiting courses in math, such as Calculus II or Proving Things in Mathematical Analysis, may be a signal that they are interested in math or have aptitude in math. Although we do not have data on the percentage of students in targeted math courses who declare the math major each year, approximately 15% of PESP students declared the math major each year, which is anecdotally higher than the percentage that declare the math major after enrollment in math courses targeted for PESP recruitment.

Underrepresented women did not enter the targeted programs in numbers equal to majority women, in contrast to underrepresented men; the reasons for this were not explained by the study. Finally, while the survey response rate was within the expected range, the study would have benefited from feedback from a larger proportion of participants.

Conclusion

A peer-based program of academic and social support for students interested in math and CS at the University of Pennsylvania was successful in attracting students, especially women and underrepresented minorities, to the targeted disciplines. The majority of participants chose to major or minor in Math and/or CS with application to a wide variety of fields. Participant feedback supported the crucial roles of social connections, relationships with underrepresented peers and mentors, demystification of Math and CS, and confidence building. Programs such as PESP are critically needed to fill needs for a skilled work-force. Future work to understand the decreased efficacy of the program for underrepresented women is needed.

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References

[1] "Women, Minorities and Persons with Disabilities in Science and Engineering. 2021," National Center for Science and Engineering Statistics, Directorate for Social, Behavioral and Economic Sciences. (National Science Foundation (U.S.)). Alexandria, VA | NSF 21-321 | April 29, 2021.

[2] E. Seymour and N. Hewitt, *Talking About Leaving: Why Undergraduates Leave the Sciences.* Boulder, CO: Westview Press, 1997.

[3] R. M. Powell, "Sundials in the shade: A study of women's persistence in the first year of a computer science program in a selective university," Ed.D. dissertation, Dept. Higher Education, University of Pennsylvania, Philadelphia, PA, 2005.

[4] S. Tobias, *They're not Dumb, They're Different: Stalking the Second Tier.* Tucson, Arizona: Research Corporation, 1990.

[5] R. M. Powell, “Improving the persistence of first-year undergraduate women in computer science,” *Proc. 39th ACM Tech. Symp. Comput. Sci. Educ., SIGCSE ‘08,* Portland, OR, USA, March 12-15. ACM SIGCSE Bulletin, vol. 40, no. 1, pp. 518-522.

[6] Bureau of Labor Statistics, U.S, Dept. of Labor, Occupational Outlook Handbook, Computer and Information Research Scientists, Dept. of Labor, Bureau of Labor Statistics. Accessed April 12, 2023. [Online] Available: https://www.bls.gov/ooh/computer-and-information-technology/computer-and-information-research-scientists.htm

[7] Bureau of Labor Statistics, U.S. Department of Labor, Occupational Handbook, Mathematicians and Statisticians, Dept. of Labor, Bureau of Labor Statistics. Accessed April 12, 2023. [Online] Available: https://www.bls.gov/ooh/math/mathematicians-and-statisticians.htm

[8] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. 2011. “Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads”. Washington, DC: The National Academies Press. https://doi.org/10.17226/12984.

[9] J. Mervis, “Better Intro Courses Seen as Key to Reducing Attrition of STEM Majors,” *Science,* vol. 330, Issue 6002, p. 306, 15 Oct 2010, [Online] Available: https://doi.org/10.1126/science.330.6002.306

[10] R. Asera, “Calculus and Community: A History of the Emerging Scholars Program: A Report of the National Task Force on Minority High Achievement,” The College Board, May, 2001, 212 713-8165.

[11] U. Treisman, “Studying Students Studying Calculus: A Look at the Lives of Minority Mathematics Students in College.” *The College Mathematics Journal*. vol. 23, No. 5, pp. 362-372, Nov. 1992. [Online] Accessed: 26/02/2009 09:30. Available: http://www.jstor.org/stable/2686410

[12] R.E. Fullilove and P.U. Treisman, “Mathematics Achievement Among African American Undergraduates at the University of California, Berkeley: An Evaluation of The Mathematics Workshop Program,” *Journal of Negro Education,* vol. *59*, no. 3, pp. 463-478, 1990.

[13] A.E. Dreyfus, “A History of Peer Led Team Learning 1990 - 2012,” *The Peer-Led Team Learning International Society: Proc. Inaugural Conf. New York City College of Technology of the City University of New York,* Brooklyn, NY, May 17-19, 2012. Available: www.pltlis.org 11201-2983.

[14] J.J. Snyder, J.D. Sloane, R.D.P. Dunk, and J. R. Wiles, “Peer-Led Team Learning Helps Minority Students Succeed,” *PLOS Biology,* 14(3), March 14, 2016. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4784972/

[15] C. Murphy, R.M. Powell, A. Cannon, and K. Parton. “Lessons Learned from a

PLTL-CS Program," *Proc. 42nd ACM Tech. Symp. Comput. Sci. Educ.*, *SIGCSE'11*, Dallas, Texas, USA, March 9–12, ACM SIGCSE Bulletin, vol. 42, no. 1, pp. 207–212.

[16] S. Horwitz and S. H. Rodger, "Using peer-led team learning to increase participation and success of under-represented groups in introductory computer science," *Proc. 40th ACM Tech. Symp. Comput. Sci. Educ., SIGCSE '09*, March 3-7, Chattanooga, Tennessee, USA. ACM SIGCSE Bulletin, vol. 41, no. 1, pp. 163–167.

[17] D. Chinn, D.K. Martin, C. Spencer, "Treisman Workshops and Student Performance in CS," Proc. 39th ACM Tech. Symp. Comput. Sci. Educ., SIGCSE 07, Covington Kentucky, USA, ACM SIGCSE Bulletin, vol. 39, no. 1, March 7–10, pp. 203-207.

[18] J. Reisel, M. Jablonski, and E. Munson, "A Study of the impact of peer-led team Learning on the First-Year Math Course Performance of Engineering Students," Techniques in Improving Mathematics Educ. STEM Curricula: Proc. 120th ASEE Annu. Conf. & Expo., Atlanta, GA, 2013.

[19] K. Carlson, D. T. Celotta, E. Curran, M. Marcus, and M. Loe, "Assessing the Impact of a MultiDisciplinary Peer-Led-Team Learning Program on Undergraduate STEM Education," Journal of University Teaching & Learning Practice, vol. 13, no. 1, 2016. https://doi.org/10.53761/1.13.1.5

[20] M. Biggers, T. Yulmaz, and M. Sweat, "Using Collaborative, Modified Peer Led Team Learning To Improve Student Success and Retention in Intro CS." Proc. 41st ACM Tech. Symp. Comput. Sci. Educ., SIGCSE'09, March 3–7, Chattanooga, Tennessee, USA, ACM SIGCSE Bulletin, vol. 41, no. 1, pp. 9-13.

[21] D. R. Arendale, "Postsecondary Peer Learning Groups Annotated Bibliography," Unpublished Manuscript, University of Minnesota College of Education and Human Development, Curriculum and Instruction Department, December 31, 2021, [Online] Available: http://z.umn.edu/peerbib