Improving high school physics outcomes for young women

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Physics program for girls (PPG) is a two-week program held every summer since 2006, with the goal of engaging young women in inquiry-based physics experiments and to connect them with female science, technology, engineering, and mathematics professional role models. The program recruits young women to participate the summer after they have taken chemistry but before they enroll in their first high school physics course. Qualitative data collected over the years about PPG have shown that the program has been positively perceived by participants; 87% said they are more prepared for physics, 95% said that they think physics might be hard, but believe they can do it, and 91% said that they are positive that they will earn an A or B in their science course. However, there has not been any analysis of PPG students' performance in their introductory physics classes. The goal of this paper is to understand this impact using chemistry and physics end of semester assessment scores for girls who participated in PPG, as well as girls who did not participate in PPG but were from the same schools and had similar demographics to the PPG participants. Girls who participated in PPG performed comparably to girls who did not participate in PPG on chemistry, but PPG girls performed better than non-PPG girls in physics. This finding persisted even after controlling for the prior year's chemistry scores.

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I. INTRODUCTION

We set out to study this physics program for young women, physics program for girls (PPG), and to determine if students who participated in this free summer camp were better prepared for their entry into high school physics the following year. In particular, we were interested in seeing if a program designed for young women by female engineers using inclusive strategies resulted in improved performance on district-wide physics exams at the end of the two semesters following the summer academy.

While summer enrichment programs abound and there are some studies on the immediate impact of summer enrichment programs on students' cognitive and affective domains [1–6], it is often challenging to understand the relationship between a student's participation in the program and longer term student outcomes. Most programs are constrained to pre- and postprogram surveys and the literature is confounded by the variety of program types,

such as day programs or residential programs, and different target audiences, such as gifted and talented students, low socioeconomic status students, different student age groups, instructor training, and the content and learning activities in the program.

In this paper, we add to the body of knowledge on how to reduce the gender gap in high school physics as we describe a two-week summer day program for young women where the content focused on the state high school physics standards. This program was developed to encourage young women to take high school physics, which is not required by the state. It was also designed to help the young women be successful in physics because it is fundamental for further studies in science, technology, engineering, and mathematics (STEM) subjects.

II. LITERATURE REVIEW

Women and minorities comprised 70% of college students, however they comprised less than 45% of STEM degrees [7]. At the undergraduate level, women earned fewer than 20% of all physics bachelor's degrees in 2012 [8] and this percentage has not changed since the 1980s [9]. The underrepresentation of women in physics also stands in contrast to their general representation across STEM degrees, where women in 2012 earned 35% of STEM bachelor's

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degrees [10]. Women are underrepresented in all levels of physics and often this becomes obvious as early as high school physics courses [11,12] where, overall, women took fewer Advanced Placement (AP) physics classes. According to McCullough, “Of all the sciences, physics is the least welcoming to women” [13]. Not only did fewer women take AP physics courses than men, they were less likely to take the AP physics exams and score lower on the AP Physics B and C exams. Interestingly, while there were significantly fewer women in AP computer science classes than men, there was no gender disparity in the AP computer science test scores.

In a recent study of over 1300 students in STEM classes at 12 different high schools, Nissan [14] found large gender differences in self-efficacy in physics, and only in physics. Furthermore, they found that girls’ self-efficacy in physics decreased after taking a high school physics course. In this study, young women in high school physics had very low and moderately low self-efficacy scores in physics compared to young men. This was not because the young men had high self-efficacy in physics, in fact male self-efficacy was found to be lower in physics than in other STEM classes. However, women’s self-efficacy in physics was half that of the men in high school classes. It is not clear why there is such a gender disparity in physics despite the many studies to try to understand this phenomenon [13,15–20]. In part, the reasons are complex and include social factors, stereotypes, school preparation, in class and out of classroom experiences, contextual experiences with physics (repairing cars, fixing electronics, playing games), and lack of role models among others. In their study [21], Hazari *et al.* found that experiences in high school physics were highly correlated to physics identity in undergraduate courses. The positive experiences for women included relevant real-world applications, conceptual understanding, peer instruction, and having an encouraging teacher. More recently, Kalender *et al.* [22] developed a physics identity model and found that external positive feedback was particularly important for young women’s physics self-competency.

The low representation of women in STEM in general, and physics in particular, is discussed in detail in the *Focused Collection on Gender in Physics* review by Blue, Traxler, and Cochran [23]. Their analysis of the literature on women in undergraduate STEM courses revealed several interesting findings: (i) there was not a consistent finding that men outperformed women in undergraduate STEM courses; (ii) women, in general, were less active participants in class; (iii) male students had a higher self-efficacy in STEM academics; (iv) gender stereotypes are tightly held by both women and men; and (v) women may feel a lower sense of belonging in STEM courses or majors. To address these issues, they suggest a framework that addresses the content, pedagogy, and psychological factors such as self-efficacy, belonging, and science identity.

While summer STEM enrichment programs abound and there are studies on the immediate impact of the program on

students’ cognitive and affective domains [1–6,24], it is often challenging to understand the relationship between the program and longer term student outcomes such as success in STEM undergraduate studies or persistence in STEM careers. Most programs are constrained to pre- and postprogram surveys and small samples sizes. In addition, a review of the literature is confounded by the variety of programs types, such as day programs or residential programs, and different target audiences such as gifted and talented students or low socioeconomic status students, the different student age groups, the instructor training, and the content and learning activities in the program. To understand the impact of summer STEM programs on student achievement in college, Kitchen *et al.* [5] collected data through a nationwide survey from 15 847 freshmen students attending colleges and universities that participated in the National Science Foundation’s STEM Talent Expansion Program (STEP). They surveyed students in required freshman English classes. The study focused on students’ interest in STEM careers, if they had attended a summer STEM program, and if so, did the program have a lot or a little real life or relevant STEM activity. They found that participating in STEM camp with real world relevancy significantly increased students’ interest in STEM careers. Interestingly, 50% of the respondents to the survey who participated in a STEM camp were female, males reported to have STEM career aspirations at twice the rate of females. The impact on participating in a STEM camp on STEM career aspirations was not found to be conditional on student demographics, but was consistent across groups. This suggests that young women enter STEM camps with lower STEM career aspirations than young men, but both groups have similar relative gains, therefore, it is important to provide young women with increased opportunities for STEM enrichment to offset these gender disparities.

Wiest *et al.* [25] presents a thorough overview of seven STEM out of school time (OST) programs for young women. This book includes descriptions of the programs along with qualitative evaluations with data sources that include open-ended and closed format surveys, interviews, focus groups, observations, journals and reflections, student artifacts, and student attendance. The book details some of the trials and tribulations of the program directors along with the voices of the young women participants. One theme throughout the book is the need for longitudinal studies on the impact of these programs on students’ performance in STEM subjects.

Measuring student performance in all subjects has long been a topic of discussion with standardized testing in the U.S. dating back to the 1930s [26]. Within the United States, a uniform system of achievement testing was implemented nationwide in 1969 with numerous changes occurring since then [27]. Many individual states have created their own curriculums and corresponding standardized

assessments [28]. At a local level, school districts often create specific benchmark exams to be given at multiple timepoints throughout the year in addition to the state or national exams [29]. These local exams are often created and validated internally without full publication. They are sometimes used as both formative and summative assessments, and ideally used to guide teachers in their current and future instruction [30]. There are numerous factors that must be considered to make valid and useful assessment instruments including reliability, validity, equity among demographic groups, alignment with curriculum [31], and more.

III. PROGRAM DESCRIPTION

The PPG program used a rich framework under the guidance of National Alliance for Partnerships in Equity Education Foundation to create a community of diverse young women who felt empowered and supported to succeed in high school physics. As described below, this program was designed by female engineers and was intentionally taught by female physics instructors because while 77% of all teachers were women, only 32% of high school physics teachers were female [32].

In 2006, PPG was developed by a group of female senior engineers to address the under representation of women in STEM by encouraging more young women to pursue STEM studies and careers. From its initial design, PPG instruction was led by women, had female engineers and scientists from industry visit to discuss their lives and careers, had female undergraduate teaching assistants, and focused on student centered active learning pedagogy in order to build a trusting cohort of young women who were interested in learning physics. Physics was chosen as the focus subject because it is a tested subject in the school district where the young women attended high school and physics is a foundational course for most STEM majors, especially engineering. Engineering is not commonly offered within Texas high schools and there is no district developed assessment for engineering. The content of the program aligned with the high school physics content students would encounter during the following fall and spring semesters. The guidelines for the state recommended high school graduation plan required students to complete four science credits prior to graduation, with one credit awarded for each completion of a year-long course. Science courses such as biology, chemistry, physics, and additional science courses accounted for one credit each and were eligible to count towards the required four science credits up to and including the students' senior year. Typically, students took one year of chemistry in the 10th grade and one year of physics in the 11th grade. The state guidelines served as a major factor in the program design and selection of participants within the PPG. Participants recruited for the initial program were students attending high-needs school districts who were entering their sophomore or junior year, had taken chemistry and planned to take their first physics

course during the fall of the year of program participation. The program also sought out students from diverse backgrounds who had previously taken an Algebra I course. A brief description detailing their earlier mathematics and science experience was included on the online application and facilitated in the selection of the final roster of students.

The goal of the summer camp experience was to increase the number of girls prepared and interested in pursuing a STEM degree when they graduate from high school. Program facilitators sought to achieve this by providing a high quality, hands-on, rigorous, problem-based mathematics and physics curriculum that engaged the girls and advanced their knowledge and skills, while making learning fun.

PPG supported these goals by (i) raising awareness of opportunities in STEM, particularly physics and engineering, (ii) boosting the confidence of girls to enter into a STEM profession, and (iii) academically preparing girls to take an introductory physics course.

A. Physics program for girls instructional lessons

The camp included ten modules shown in Table I. Each module focused on a specific physics concept or skill through an inquiry-based activity designed to introduce the general understanding of the given topic to the girls within the PPG. They were supported by student hands-on activities, videos, and deep discussions over the given topic. Students typically worked in groups of four with each group rotating members so they could experience working with different classmates during the two-week summer experience.

The PPG program's hands-on activities made the learning relevant to the girls' lives. For instance, one of the first topics that the participants experienced is the circuitry module. This series of lessons was designed for the girls to investigate the nature of electrical circuits. Each section of the module built upon the other starting with a challenge such as to light a bulb using one battery and a piece of wire and gradually move toward introducing more complicated tools including digital multimeters and power supplies to measure amps and voltage. The girls eventually created puzzle projects (discovery circuits) demonstrating how open circuits affect voltage in parallel and series circuits. They also introduced resistive elements that would challenge their classmates' understanding of combination circuits. Once these puzzles were created, they then swapped with a neighboring group to challenge their understanding of circuits.

B. Growth mindset facilitation

The PPG program recognized the importance of having facilitators who are comfortable with both physics and engineering initiatives in addition to the challenges associated with recruiting and supporting adolescent girls within physics. Because of this, great care was taken in

TABLE I. Sample schedule of PPG.

	Physics content lesson	Support activities
Day 1	Circuits lab voltage lab, series circuit lab	Growth mindset discussion, logic puzzle, design challenge #1
Day 2	Parallel circuit lab making meaning lab	Logic puzzles, stereotype threat discussion, stem guest speaker: computer engineer
Day 3	Combination circuit maker lab discovery circuits lab	Introduction to coding, campus tour, design challenge #2
Day 4	Match the graph activity position and velocity lab part 1	Spatial thinking activity, research lab tour, stem guest speaker: Martian Geologist
Day 5	Position and velocity lab part 2	STEM field trip experience
Day 6	Design challenge balloon rockets collision point lab	Gender equity discussion, research lab tour, logic puzzles
Day 7	Feather and a penny demo video tape timer lab	Guest speaker: University admissions
Day 8	Vector treasure hunt lab force investigations stations	Gender equity discussion, logic puzzles
Day 9	Flying pigs lab, bullet drop video ap physics question review	Design challenge, logic puzzles, guest speaker: naval architect
Day 10	Physics activity stations liquid N2 demos, dart gun lab	Student survey, group pictures

the recruitment and selection of the program facilitators. The program was held at a major university and the facilitators included a physics college professor, a K-12 grade level science instructor, and an undergraduate student who was knowledgeable in physics and engineering concepts. The facilitators were specifically chosen for their ability to reinforce content knowledge and make connections between school and PPG learning.

In addition to leading engaging learning experiences, the facilitators were also well trained in discussing and demonstrating the concept of growth mindset and its importance in their development as future leaders in STEM. At the onset of the program, students were introduced to the concept of growth mindset and its effect on learning, problem solving, and creativity. The girls were encouraged to “think about their thinking” when challenges occurred. They also had instructional techniques in play that encouraged those who finished early to offer support to others who may be struggling to understand the given concept or solving problems. This was done with the hope of having the girls discover that mistakes are part of the scientific process and that errors can lead to more collaboration which in turn leads to effective problem solving and discovery. PPG emphasized that as the girls would progress in physics and engineering courses, their most significant experiences would be the most demanding ones and that they should not feel alone during the learning process when they engage in their first high school physics course.

C. Guest speakers and field experiences

PPG participants had a unique opportunity to interact with diverse female STEM leaders. By bringing in guest speakers from STEM fields, the girls had the opportunity to explore career options and to ask questions of women who, like them, were interested in STEM concepts at a young age. It is known that role models matter and having female role models in STEM careers can help young women

envision themselves in those careers [13,33,34]. However, physics teachers in high school and college tend to be men, so there are often few opportunities for young women to interact with female physicists. Research conducted in 2013 shows 37% of high school physics teachers were women compared to 29% in 2001. This percentage has increased overtime, but still remains relatively low when you consider more than three-quarters of the U.S public school teachers are female [35]. In addition, research by Dasgupta suggests that having role models of the same gender can inoculate students from stereotype threat [36]. In PPG, the female guest speakers had multiple opportunities to informally meet and discuss their paths to their current career choice, as well as to describe life outside of their work environments. These interactions allowed for the girls to begin to eliminate any negative ideas about what it means to be a female scientist or engineer. The guest speakers in PPG were especially effective because their demographics reflected those of the students. PPG was very explicit in its approach to recruiting partners and role models from varied ethnic and socioeconomic groups who are underrepresented in STEM fields.

PPG also set up multiple field experiences so the girls could see STEM work environments and interact with the women within these workplaces. Field trips gave participants a chance to informally interact with one another and helped create additional support groups outside the program. PPG groups were given the opportunity to tour a STEM work facility. As previously mentioned, the Houston PPG program is held on the campus of Rice University, a comprehensive research university that offers over 50 undergraduate majors across six divisions of study including engineering, architecture, and natural sciences. During the summer, PPG students were allowed to tour the campus and have additional guided tours inside research labs to help better understand the work currently being done that will impact their futures. This also gave the PPG girls a chance to recognize that becoming a college student

majoring in a STEM field could be a realistic part of their future.

IV. METHODS

A. Sample and procedure

We requested chemistry and physics assessment data for school years (SY) 2013–2014 through 2017–2018 from a large school district in Texas where the PPG program was administered. These data were requested for both the PPG students and female peers of PPG students who did not participate in PPG. A group of non-PPG students was identified by random selection of the larger set of data provided such that the control group's attendance at the same schools and physics classrooms were in the same proportions as the PPG students. This identified cohort served as the control group students in this quasiexperimental design. Over 90% of students attended high-poverty schools (as indexed by proportion of students receiving free or reduced cost lunch). In total, we received data on 925 (PPG = 174, control = 751) unique students. However, some data were missing with some students having only chemistry and some having only physics. In Table II, we present the data patterns for chemistry and physics by PPG status. Students were designated as having data if they had data in at least one semester even though both courses are two semesters long. As seen in Table II, about half of non-PPG students, and one-third of PPG students had data on both chemistry and physics.

B. Measures

At the end of the fall and spring semesters, the district assessed all chemistry and physics students with a district-wide benchmark assessment, referred to as the end of semester assessment (ESA). This assessment accounted for 15% of the students' course grade. The assessment was proprietary and the district did not publish psychometric information on the assessment. However, they did provide some information on assessment content, item type, and some sample items from the most recent benchmark assessments. All assessment items were conceptually linked to one of the state standards for Texas public schools, known as Texas Essential Knowledge and Skills (TEKS). The chemistry ESA addressed 17 TEKS with

2 items per TEKS for all but one of the TEKS for a total of 33 questions, whereas the physics ESA assessed 14 TEKS with 2 items per TEKS for a total of 28 questions. Both assessments had a maximum score of 100 points.

C. Analyses

To examine if PPG and non-PPG students were comparable in chemistry exam scores, we compared chemistry performance for PPG students with non-PPG students controlling for school year using generalized linear mixed modeling. We fit two models: (i) where semester exam scores served as outcomes and (ii) where we averaged fall and spring exam scores. In the first model, we fit a random intercept for students and teachers to account for the fact that semester scores were nested within students and students were nested within teachers. We estimated fixed effects for semester, and PPG status. The second model was similar to the first except that we had one record per student and as such did not investigate the effect of semester or fit a random intercept for students.

To examine the impact of PPG we compared physics exam performance of PPG students with non-PPG students using generalized linear mixed modeling just as was done above. In these models, we examined the effect of PPG participation controlling for prior chemistry performance. Two models were fit similarly to the chemistry models above: (i) where semester exam scores served as outcomes and (ii) where fall and spring exam scores were averaged.

V. RESULTS

A. Missing data analysis

Prior to the investigation of the impact of PPG, we conducted a missing data analysis. As can be seen in Table II, missing subject level data were somewhat substantial with only 47% of non-PPG students and 33% of PPG students having at least one chemistry and one physics record. We wanted to see if missingness is systematic by PPG group designation. For example, if non-PPG students with missing physics data scored better on chemistry relative to PPG students, then this could indicate that the strongest non-PPG students did not have present physics data and as such, the performance on physics for the non-PPG students could be negatively biased. On the other hand, if all students (both non-PPG and PPG) without physics data performed better on chemistry, then both groups' scores would be negatively biased, but equally so. To examine potential effects of missing data we fit a model where chemistry scores were predicted by PPG group status, a present physics data vector (0 = missing, 1 = present), and the interaction of these two variables. In examining the results of this model, we found that students with missing data on physics had higher chemistry scores [estimate = 5.0, $t(617) = 2.87$, $p = 0.004$]. However, we found both the effect of PPG status and

TABLE II. Data patterns for chemistry and physics by PPG status.

Treatment	Chemistry	Physics	Count
Control	No	Yes	148
	Yes	No	249
	Yes	Yes	354
Treatment	No	Yes	56
	Yes	No	60
	Yes	Yes	58

TABLE III. Descriptive statistics for all chemistry and physics data.

PPG status	Variable	<i>N</i>	Mean	Std. dev.
Control	Chemistry fall	602	78.36	11.32
	Chemistry spring	594	76.30	11.38
	Physics fall	500	72.67	9.28
	Physics spring	488	71.57	8.63
Treatment	Chemistry fall	118	80.21	10.33
	Chemistry spring	118	77.97	11.19
	Physics fall	114	76.55	9.02
	Physics spring	112	75.59	8.04

TABLE IV. Descriptive statistics for students with both chemistry and physics data.

PPG status	Variable	<i>N</i>	Mean	Std. dev.
Control	Chemistry fall	353	73.54	9.38
	Chemistry spring	351	72.64	10.88
	Physics fall	353	74.41	9.58
	Physics spring	346	72.76	8.79
Treatment	Chemistry fall	58	76.12	8.98
	Chemistry spring	58	73.69	11.82
	Physics fall	58	79.47	8.91
	Physics spring	58	73.84	8.46

the interaction between missingness and PPG status to be nonsignificant [PPG status: $F(1, 617) = 0.34$, $p = 0.560$; interaction: $F(1, 617) = 2.71$, $p = 0.100$], which suggest that the effect of missingness on chemistry did not depend on treatment status. In other words, both PPG and non-PPG students without physics data performed better in chemistry. Because the effect of missingness did not depend on PPG status, the missingness should have minimal impact on the investigation of the effect of PPG.

B. Descriptive statistics

Sample size, means, and standard deviations for the chemistry and physics scores can be seen in Tables III and IV. The table displays the scores for all available data in Table III, and students with at least one chemistry and one physics score in Table IV.

C. Prior chemistry performance

In this section we investigate if PPG and non-PPG students performed comparably in chemistry in the school year prior to when the students participated in the PPG program. Model results for the two generalized linear mixed models investigating chemistry performance can be seen in Tables V and VI. The estimate for the intercept is the mean performance on chemistry for the treatment students in spring (the reference category). The estimate for fall was the mean adjustment for fall scores. The control effect was the mean adjustment for non-PPG students. As can be seen in Tables V and VI, the mean adjustment for the non-PPG students on chemistry performance was a downward adjustment by a little less than two points. However, the effect is nonsignificant and as such we cannot conclude that this effect represents anything beyond typical sampling variability. Thus, it would be reasonable to conclude that PPG and non-PPG students performed comparably on the chemistry assessment.

D. Physics performance

In this section, we investigate the impact of the PPG program on physics performance in the school year following participation in PPG. The interpretation of the intercept, semester effects, and PPG status effects are the same as in the model above. The interpretation for the estimate for chemistry is the change in physics scale scores per one-unit change in chemistry scale scores. Full model results can be seen in Tables VII and VIII. Even after controlling for initial

TABLE V. Model results for semester chemistry performance.

Effect	Semester	PPG status	Estimate	Standard error	DF	<i>t</i> value	Pr > <i>t</i>
Intercept			75.3562	1.5507	5	48.60	<0.0001
Semester	Fall		0.9602	0.5210	393	1.84	0.0661
Semester	Spring		0.0000	...	...	...	...
PPG status		Control	−1.7760	1.1966	393	−1.48	0.1386
PPG status		Treatment	0.0000	...	...	...	...

TABLE VI. Model results for annual chemistry performance.

Effect	PPG status	Estimate	Standard error	DF	<i>t</i> value	Pr > <i>t</i>
Intercept		75.7297	1.4965	42	50.61	<0.0001
PPG status	Control	−1.9185	1.1956	367	−1.60	0.1094
PPG status	Treatment	0.0000	...	...	...	...

TABLE VII. Model results for semester physics performance.

Effect	Semester	PPG status	Estimate	Standard error	DF	<i>t</i> value	Pr > <i>t</i>
Intercept			56.4624	2.5967	5	21.74	<0.0001
Chemistry			0.2484	0.029 93	392	8.30	<0.0001
Semester	Fall		2.0056	0.5518	392	3.63	0.0003
Semester	Spring		0.0000	...	...	...	...
PPG status		Control	−3.3128	0.8728	392	−3.80	0.0002
PPG status		Treatment	0.0000	...	...	...	...

TABLE VIII. Model results for annual physics performance.

Effect	PPG status	Estimate	Standard error	DF	<i>t</i> value	Pr > <i>t</i>
Intercept		47.7655	2.9901	42	15.97	<0.0001
Chemistry		0.3790	0.035 83	366	10.58	<0.0001
PPG status	Control	−3.0704	0.8669	366	−3.54	0.0004
PPG status	Treatment	0.0000	...	...	...	...

differences in chemistry performance, there was a significant effect for PPG status. The PPG students outperformed the non-PPG students by over three points on the standardized physics assessment. Thus, it appears that participation in the PPG program was associated with better performance on the next year's physics assessments, even after accounting for levels of chemistry knowledge. We also note that students who performed better in chemistry also tended to perform better in physics, and all students performed better on both chemistry and physics fall assessments than the spring assessments.

E. Stability analyses

Little information was available from the school district regarding the consistency of the ESA across years. As such

we conducted a within year stability analysis of physics performance. SYs 2014–2015 and 2015–2016 were the only two years with large samples of both PPG and non-PPG students with $N = 200$ students in SY 2014–2015 and $N = 247$ in SY 2015–2016. Although the magnitude of effects for PPG differs by three points, the models' results for both years were comparable to those of the overall model with regard to significant effects for prior chemistry performance, season, and treatment, with PPG students outperforming non-PPG students. See Tables IX and X for full results.

VI. SUMMARY AND DISCUSSION

In this study, we investigated the impact of a two-week summer program for young women who were going to take

TABLE IX. Stability model results for semester physics performance by year for SY 2014–2015. Note that the intercept represents the estimate for the control group in the fall.

Effect	Estimate	Standard error	DF	<i>t</i> value	Pr > <i>t</i>
Intercept	53.25	8.19	2	6.5	0.0228
Chemistry	0.34	0.10	94	3.21	0.0018
Spring	1.43	1.41	94	−1.01	0.3135
By PPG status: Treatment	5.94	1.88	94	−3.15	0.0022

TABLE X. Stability model results for semester physics performance by year for SY 2015–2016. Note that the intercept represents the estimate for the control group in the fall.

Effect	Estimate	Standard error	DF	<i>t</i> value	Pr > <i>t</i>
Intercept	58.95	3.87		15.25	...
Chemistry	0.17	0.04	119	3.95	0.00
Spring	−5.88	0.85	119	6.90	<0.001
PPG status: Control	2.49	1.17	119	−2.14	0.03

introductory high school physics in the following school year. Our overarching aim was to determine if the PPG program had a positive impact on later performance in high school physics. To conduct the evaluation, we performed four sets of analyses: (i) an investigation of the missing data patterns and potential influences on chemistry performance, (ii) an investigation of chemistry ESA exam scores to investigate if PPG and non-PPG students performed comparably prior to the PPG program, (iii) an investigation of physics ESA exam scores to evaluate the impact of participation in the PPG program on later physics performance, and (iv) to evaluate the stability of the analyses.

When investigating missing data patterns, we found that students with missing physics data performed better on chemistry, but that was true for both PPG and non-PPG students. Although this finding could influence the estimation of overall physics performance for all students, this downward bias appears to be uniform and should not impact the estimation of the effects of being in the PPG program.

In our investigation of chemistry exam performance, we found that, although non-PPG students performed numerically lower than PPG students, the difference was nonsignificant. This nonsignificant finding suggests that the groups are, in fact, comparable in the larger population and that the difference is what could be expected due to sample fluctuations. Despite the effect being nonsignificant, we chose to include chemistry performance in the model predicting physics exam performance in order to control for any potential differences between the groups on chemistry performance.

When examining physics performance, we found that PPG students outperformed non-PPG students even after controlling for chemistry performance. PPG students performed three points better than non-PPG students on the district physics assessment. Although three points may seem like a small effect, we note that the PPG program was only two weeks long and occurred over the summer. Given the short duration of the program and that the physics ESA exam occurred at a distal time point, this three point difference was relatively substantial.

Because we found that students who participated in PPG outperformed comparison students on their district wide physics assessments, we want to theorize about why the program had this impact. One facet of the program was the safe environment created from the first day. Participants were told that it was a space where they are free to question and make mistakes. The young women who attended PPG typically did not know each other and were quiet at first. However, the student centered, hands-on, group work drove conversations as students began to share their observations. This camaraderie built over the two-week program as the young women became more comfortable discussing what they understood and what they were confused about in this safe all female environment. Open discussions about imposter syndrome and the growth mindset framework

set norms that this was a program in which everyone would try, everyone would seek to learn from one another, and that there were always opportunities to develop and grow personally in the areas where they may need additional assistance. Furthermore, bringing in female STEM leaders to talk about their careers and lives, allowed them to serve as inspirational role models and answer questions on career path, work-life balance, and challenges that they had faced. Lastly, the participants enjoyed the active learning aspects of the program where they had time to problem solve, write, and reflect on all components of the program in small group and large group settings. This is reflected in the very positive feedback reported in the 2018 evaluation report where 96% of the attendees rated PPG positively [37]. Therefore, we summarize that girls who participated in PPG performed higher in their high school physics district wide assessments because the program provided them with a safe environment to learn, a cohort of peers to learn with, engaging hands-on learning experiences, and female role models to inspire them to study physics.

A. Limitations

One limitation is the lack of random assignment or a randomized control trial (RCT). Thus, it is possible that the positive effects were related to self-selection bias. We do note that, unlike targeted curriculum interventions, voluntary summer programs do not lend themselves to evaluation with RCTs. It is nearly impossible to randomize some students to attend summer programs such as this. Although it would have been optimal to use an RCT design, we were able to identify female students attending the same physics sections as the girls from the PPG program, as well as controlling for prior chemistry performance. This blocking by class section, and controlling for prior science knowledge helped alleviate concerns with selection bias.

A second limitation pertains to the lack of psychometric information about the ESA. Although this information would have been useful in evaluating the validity and reliability of the assessment, the district would not share this information with our team, nor would they provide us with item level information. Thus, we were not able to generate reliability statistics ourselves. We note that, though we could not establish reliability in the form of coefficient alpha, the stability analyses demonstrated reliability of statistically significant relations across years.

VII. NEXT STEPS

PPG moving forward will focus on replicating the program with other targeted content areas beginning with chemistry and including science content assessments for the students. PPG would also like to implement aspects of their program with teachers during the school year through professional development. The professional development model for implementation would be to work with teachers

located in school districts where the students participating in the summer program are recruited from and bring them in before the PPG begins to receive professional development on the PPG content. The teachers would then help facilitate the PPG summer camp and then take the activities and lessons back to their classrooms during the school year. The final step for PPG is to work on leveraging existing or new funding sources to continue to spread the PPG mission. One way this can be accomplished is to leverage proposals from various colleges and universities all over the

United States as they submit funding requests to various funding agencies. The PPG program has the data and resources to be added to proposals and show impact in communities all over the country.

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- [1] J. C. Adams, *Scratching Middle Schoolers' Creative Itch* (Association for Computing Machinery, Milwaukee, WI, 2010), pp. 356–360.
 - [2] C. Chen, K. Tomsovic, and M. Aydeniz, Filling the pipeline: Power system and energy curricula for middle and high school students through summer programs, *IEEE Trans. Power Syst.* **29**, 1874 (2014).
 - [3] M. E. Elam, B. L. Donham, and S. R. Solomon, An engineering summer program for underrepresented students from rural school districts, *J. STEM Educ. Innov. Res.* **13**, 35 (2012), <https://www.jstem.org/jstem/index.php/JSTEM/article/view/1619/1437>.
 - [4] M. Kim, A meta-analysis of the effects of enrichment programs on gifted students, *Gifted Child Quart.* **60**, 102 (2016).
 - [5] J. A. Kitchen, G. Sonnert, and P. M. Sadler, The impact of college- and university-run high school summer programs on students' end of high school STEM career aspirations, *Sci. Educ.* **102**, 529 (2018).
 - [6] N. Timme, M. Baird, J. Bennett, J. Fry, L. Garrison, and A. Maltese, A summer Math and Physics program for High School students: student performance and lessons learned in the second year, *Phys. Teach.* **51**, 280 (2013).
 - [7] H. Blackburn, The status of women in STEM in higher education: A review of the literature 2007–2017, *Sci. Technol. Librar.* **36**, 235 (2017).
 - [8] Bachelor's degrees earned by women, by major, APS Physics. (n.d.). <https://www.aps.org/programs/education/statistics/womenmajors.cfm> (accessed March 15, 2020).
 - [9] P. Mulvey and S. Nicholson, *Physics Bachelor's Degrees: Results for the 2010 Survey of Enrollments and Degrees* (American Institute of Physics, New York, 2012).
 - [10] T. D. Snyder and S. A. Dillow, *Digest of Education Statistics 2011* (National Center for Education Statistics, Washington, DC, 2012).
 - [11] C. Riegle-Crumb and C. Moore, The gender gap in high school physics: Considering the context of local communities, *Soc. Sci. Q.* **95**, 253 (2014).
 - [12] R. M. Lock and Z. Hazari, Discussing underrepresentation as a means to facilitating female students' physics identity development, *Phys. Rev. Phys. Educ. Res.* **12**, 020101 (2016).
 - [13] L. McCullough, Women in physics: A review, *Phys. Teach.* **40**, 86 (2002).
 - [14] J. M. Nissen, Gender differences in self-efficacy states in high school physics, *Phys. Rev. Phys. Educ. Res.* **15**, 013102 (2019).
 - [15] R. Skibba, Women in physics, *Nat. Rev. Phys.* **1**, 298 (2019).
 - [16] L. J. Sax, K. J. Lehman, R. S. Barthelemy, and G. Lim, Women in physics: A comparison to science, technology, engineering, and math education over four decades, *Phys. Rev. Phys. Educ. Res.* **12**, 020108 (2016).
 - [17] T. Espinosa, K. Miller, I. Araujo, and E. Mazur, Reducing the gender gap in students' physics self-efficacy in a team- and project-based introductory physics class, *Phys. Rev. Phys. Educ. Res.* **15**, 010132 (2019).
 - [18] M. Mears, Gender differences in the Force Concept Inventory for different educational levels in the United Kingdom, *Phys. Rev. Phys. Educ. Res.* **15**, 020135 (2019).
 - [19] Z. Y. Kalender, M. Emily, D. S. Christian, J. N.-M. Timothy, and S. Chandralekha, Gendered patterns in the construction of physics identity from motivational factors, *Phys. Rev. Phys. Educ. Res.* **15**, 020119 (2019).
 - [20] R. Henderson, J. Stewart, and A. Traxler, Partitioning the gender gap in physics conceptual inventories: Force Concept Inventory, Force and Motion Conceptual Evaluation, and Conceptual Survey of Electricity and Magnetism, *Phys. Rev. Phys. Educ. Res.* **15**, 010131 (2019).
 - [21] Z. Hazari, G. Sonnert, P. M. Sadler, and M.-C. Shanahan, Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study, *J. Res. Sci. Teach.* **47**, 978 (2010).
 - [22] Z. Y. Kalender, M. Emily, D. S. Christian, J. N.-M. Timothy, and S. Chandralekha, Why female science, technology, engineering, and mathematics majors do not identify with physics: They do not think others see them that way, *Phys. Rev. Phys. Educ. Res.* **15**, 020148 (2019).
 - [23] J. Blue, A. Traxler, and G. Cochran, Resource Letter: GP-1: Gender and Physics, *Am. J. Phys.* **87**, 616 (2019).
 - [24] I. Pivkina, E. Pontelli, R. Jensen, and J. Haebe, Young women in computing: Lessons learned from an educational and outreach program, *ACM SIGCSE Bull.* **41**, 509 (2009).
 - [25] L. R. Wiest and J. E. Sanchez, *Out-of-School-Time STEM Programs for Females: Implications for Research and*

- Practice Volume I: Longer-Term Programs* (Information Age Publishing, Charlotte, NC, 2017).
- [26] P. Alcocer, N. E. Policy, and P. Intern, History of Standardized Testing in the United States, NEA. <http://www.nea.org/home/66139.htm> (accessed April 27, 2020).
- [27] About NAEP, National Center for Education Statistics, <https://nces.ed.gov/nationsreportcard/about/> (accessed April 27, 2020).
- [28] L. Darling-Hammond, Standards, accountability, and school reform, *Teach. Coll. Rec.* **106**, 1047 (2004).
- [29] K. E. Bulkley, J. B. Christman, M. E. Goertz, and N. R. Lawrence, Building with benchmarks: The role of the district in Philadelphia's benchmark assessment system, *Peabody J. Educ.* **85**, 186 (2010).
- [30] M. Perie, B. Gong, and J. Wurtzel, The Role of Interim Assessments in a Comprehensive Assessment System: A Policy Brief, Achieve/Aspen/Center for Assessment, 2007.
- [31] S. P. Klein and L. S. Hamilton, *Rand Education (Institute), Large-Scale Testing: Current Practices and New Directions* (RAND Education, Santa Monica, CA, 1999).
- [32] S. White and C. Langer Tesfaye, *Female Students in High School Physics: Results from the 2008-09 Nationwide Survey of High School Physics Teachers* (American Institute of Physics, New York, 2011).
- [33] S. Cheryan, J. O. Siy, M. Vichayapai, B. J. Drury, and S. Kim, Do Female and Male Role Models Who Embody STEM Stereotypes Hinder Women's Anticipated Success in STEM?, *Soc. Psychol. Personality Sci.* **2**, 656 (2011).
- [34] S. D. Herrmann, R. M. Adelman, J. E. Bodford, O. Graudejus, M. A. Okun, and V. S. Y. Kwan, The effects of a female role model on academic performance and persistence of women in STEM courses, *Basic Appl. Soc. Psychol.* **38**, 258 (2016).
- [35] A. M. Porter and R. Ivie, *Women in Physics and Astronomy, 2019* (American Institute of Physics, New York, 2019).
- [36] N. Dasgupta, Ingroup Experts and Peers as Social Vaccines Who Inoculate the Self-Concept: The Stereotype Inoculation Model, *Psychol. Inquiry* **22**, 231 (2011).
- [37] Design Connect Create: 2018 Report, <https://designconnectcreate.org/about/>.