Digging Deeper into Student–Teacher–Scientist Partnerships for Improving Students' Achievement and Attitudes about Scientists

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Abstract

A feature of student–teacher–scientist partnerships (STSPs) involves students working with scientists for the purpose of helping them learn more about how scientists work and think. Previous research on STSPs has generally focused on identifying the best practices of partnerships and on identifying challenges of these partnerships. The study reported here employed a cluster-randomized trial design to test the effectiveness of the PlantingScience STSP that combines high-quality curriculum, teacher preparation, and online mentoring by professional scientists. The results of the current study show that students who participated in the PlantingScience STSP showed significant improvements in science content knowledge and attitudes about scientists compared with students in the control group. The study sample was highly representative, demographically, to the U.S. population of high schools. These results add to the limited empirical evidence about the effectiveness of STSPs on student outcomes related to science achievement and attitudes.

Key Words: *student–teacher–scientist partnership; scientist mentors; learning communities; attitudes about scientists.*

○ Introduction

According to the *Framework for K–12 Science Education* (National Research Council, 2012), science education involves the interplay of several components including curriculum, effective instruction, and teacher development. The *Framework* also calls for students to learn and experience science practices. By engaging in science practices, students gain a deeper understanding of how scientists work – including how they devise and test hypotheses, build a body of evidence, and communicate and convey their findings.

One way of helping students learn more about how scientists work and think is by having students interact directly with scientists. Student–teacher–scientist partnerships (STSPs) and student–scientist partnerships (SSPs) are formats for enabling this interaction between students and scientists. In STSPs, teachers bring both science content and pedagogical knowledge to facilitate student learning and scientists contribute both content knowledge and expertise in scientific research. SSPs have less defined roles for teachers. These programs take different forms ranging from those that are led by scientists to those in which the students take the lead for the design of the experiment (Sadler et al., 2009; Tinker, 1997).

Research on STSPs and SSPs has generally focused on identifying the best practices of partnerships and on identifying challenges that such partnerships face (Carr, 2002; Harnik & Ross, 2003; Lawless & Rock, 1998; Ledley et al., 2003; Moreno, 2005; Moss et al., 1998; Peker & Dolan, 2012; Schwartz et al., 2004; Tinker, 1997; Wormstead et al., 2002). Empirical evidence about STSPs is less common (Sadler et al., 2009). Published studies report mixed but generally positive empirical changes in science achievement and attitudes for students participating in STSP (Andrews et al., 2020; Dailey et al., 2018; Hedley et al., 2013; Hellgren & Lindberg, 2017; Houseal et al., 2014; Li et al., 2010; Shein & Tsai, 2015). While the results from these previous studies are encouraging, small sample sizes and the lack of a randomly assigned comparison group limit their impact.

The PlantingScience STSP evaluated here has been active since 2005 and has been the subject of multiple research studies. Over 26,000 students, 400 teachers, 350 PlantingScience liaisons, and 800 scientist mentors have participated in one or more of the 10 available investigation themes (modules). Previous case-study research has shown qualitatively how the PlantingScience program can positively affect students' engagement in inquiry, motivation, and attitudes toward science (Scogin, 2014; Scogin & Stuessy, 2015; Scogin, 2016). The current study was designed to quantitatively measure the effectiveness of the PlantingScience STSP to improve student achievement and attitudes about scientists using a large and randomly assigned sample of teachers and students.

○ Methods

Study Design

This study used a cluster-randomized trial design with teachers (and their biology students by association) randomly assigned to participate in either the Power of Sunlight module or the control

The American Biology Teacher, Vol. 85, No. 7, pp. 379–389, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2023.85.7.379.

condition where students were taught the concepts of photosynthesis and respiration through business-as-usual (BaU) instructional methods. The BSCS Science Learning institutional review board reviewed and approved all research procedures, consent/assent forms, and evaluation instruments prior to the beginning of the research study. Students participating in the study provided assent and their parents or guardians provided consent.

Recruitment

Teachers

Teachers for this study were recruited through announcements through the BSCS Science Learning (BSCS) website and e-communications. These announcements were then shared through various listservs. Interested teachers submitted an application to express their interest. The goal was to recruit teachers from around the country that served diverse student populations. The application asked for a variety of information, including the class sections they teach (to ensure that the topics of photosynthesis and cellular respiration were appropriate for the curriculum) and the grade level of their students. Teachers who met the necessary criteria were randomly assigned to either the treatment group or the control group.

To qualify for this study, teachers agreed to teach photosynthesis and cellular respiration during the fall semester. Teachers in the treatment group agreed that they would not include instruction on these topics prior to beginning the Power of Sunlight module. Most if not all students would have had some instruction about these topics in earlier grades, but not during the course in which they were enrolled during the study.

Before teachers participated in any study activities, BSCS Science Learning applied for and received formal approval from each teacher's school or district to take part in the study. This ensures that all district policies and regulations were met.

PlantingScience liaisons (liaisons)

PlantingScience liaisons were recruited through e-mail and social media announcements from the Botanical Society of America and American Society of Plant Biologists. The announcements targeted early-career biologists with an interest in plant science, education, and outreach. Participants ranged from graduate students to early-career scientists (in faculty or nonacademic positions).

Scientist mentors (mentors)

Scientist mentors were recruited from the membership of plant science scientific societies. Mentors volunteer by completing a profile on the PlantingScience.org website and indicating their availability to mentor during a particular session. At the time of the study, the mentor gallery included a diverse group of approximately 500 scientists working in plant-related fields, ranging from graduate students through emeritus faculty and including plant scientists in nonacademic jobs.

Sample Characteristics

Before starting the research study, teachers in both groups self-reported their frequency of using common teaching practices. These self-reports showed the frequency of these practices was similar between the groups. Teachers in both groups on average reported engaging in the following practices frequently (once or twice a week or more): class-wide discussion, small-group discussion, hands-on/laboratory activities, requiring evidence to support claims, have students represent or analyze data using tables/charts/graphs (Taylor et al., 2022). This suggests that the BaU teachers likely used teaching strategies and practices similar to those used by the teachers using the Power of Sunlight module. Therefore, the improvements in student outcomes in the treatment group are more likely to be attributable to the Power of Sunlight module implementation rather than differences in classroom practices themselves.

The student sample characteristics of the analytic sample (post-attrition sample) are provided in Table 1. After attrition, there were about twice as many students in the control group (n = 1021) as in the treatment group (n = 514). The baseline achievement and attitudes means were very similar between the two groups, with the control group having a slightly less variable performance, and scoring approximately one point higher. In terms of student characteristics, the percentage of students with each characteristic were roughly similar between treatment and control groups, but some differences did exist. For example, there with slightly more 9th grade students in the treatment group (46% vs. 41%) and more

Table 1. Baseline and group equivalence of students in the study ($n_T = 514$, $n_C = 1021$).

Baseline Outcome or Student Characteristic	Treatment		Control	
	Mean or Frequency	SD or %	Mean or Frequency	SD or %
Baseline achievement	44.46	8.19	45.60	7.89
Baseline attitudes	50.76	6.19	51.75	6.07
Female	277	54	606	59
English language learner	61	12	229	22
Receives free or reduced-price lunch	153	30	357	35
Asian	48	9	89	9
Black or African American	52	10	64	6
American Indian or Alaska Native	49	10	43	4
Native Hawaiian or Other Pacific Islander	9	2	19	2
Hispanic or Latino/Latina	80	16	367	36
White	395	77	623	61
Other race	12	2	16	2
Grade 9	234	46	419	41
Grade 10	151	29	218	21
Grade 11	87	17	216	21
Grade 12	42	8	168	16

12th grade students in the control group (16% vs. 8%). There were more English language learners in the control group (22% vs. 12%). All baseline differences, regardless of size, were accounted for in the statistical model for estimating impacts (see section Multilevel modeling).

The Generalizer software (Tipton & Miller, 2015) was used to assess the similarity between the student composition of high schools in this study and the student composition of the 20,088 regular (nonspecialized) high schools in the United States for which there were Common Core data in 2012–2013. The software computed a generalizability index of 0.949 for the similarity of the student compositions of the regular high schools in the nation and the 48 (out of 51) study schools that could be located in the 2012–2013 Common Core database. Values greater than 0.90 indicate that the schools participating in the study are as similar to the U.S. population of regular high schools (with respect to student composition variables selected) as would be a random sample of the same size.

Treatment Conditions

The Power of Sunlight Condition

The PlantingScience Power of Sunlight STSP combines high-quality curriculum, online mentoring by professional scientists, and collaborative teacher/liaison professional learning (PL). The first component of the STSP is high-quality curriculum. The high school PlantingScience Power of Sunlight module was chosen as the curriculum component for this study because it addresses the important concepts of photosynthesis and cellular respiration. These concepts are key disciplinary core ideas (DCIs) related to matter and energy in the *Next Generation Science Standards* (NGSS Lead States, 2013). These are also topics about which students hold many persistent misconceptions (see Table 2).

The Power of Sunlight module includes instructional materials for students and implementation support materials for teachers. Students first build a foundation in both the science content and scientific practices through a series of thought investigations, guided investigations, and semi-guided investigations. This series prepares students to design and carry out a student-initiated investigation (as a team of three to five students) based on their own research questions. The module culminates with the class generating a shared storyboard to synthesize what they have learned throughout their

Table 2. Common misconceptions related to photosynthesis and cellular respiration.

Scientifically Invalid Idea	References
Photosynthesis occurs in plants and cellular respiration occurs only in animals.	Driver et al. (1993), Parker et al. (2012), Amir and Tamir (1994), and Köse (2008)
Plants photosynthesize during the day and cellular respiration occurs at night.	Galvin et al. (2015), Hershey (2004), Parker et al. (2012), Marmaroti and Galanopoulou (2006), and Yenilmez and Tekkaya (2006)
Energy is created and/or destroyed in photosynthesis and/or cellular respiration.	Driver et al. (1993) and Galvin et al. (2015)
Plants obtain food and nutrients from the soil and use them to grow in mass, rather than using carbon dioxide from the air.	Driver et al. (1993), Galvin et al. (2015), Wood-Robinson (1991), Barman et al. (2006), Roth and Anderson (1987) , Parker et al. (2012), Eisen and Stavy (1988)

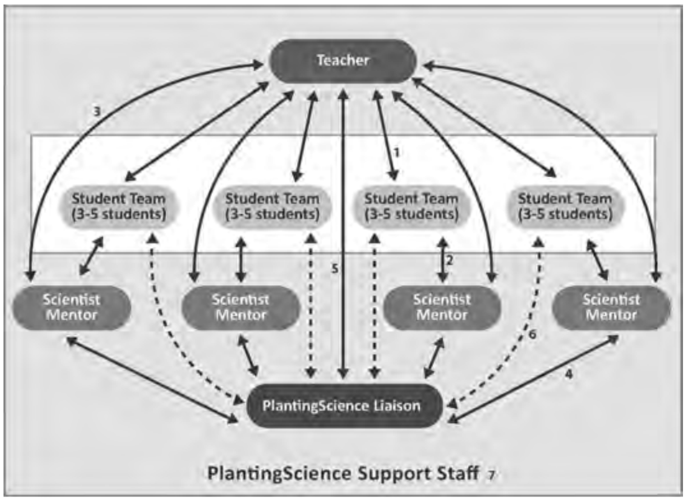

Figure 1. PlantingScience modules involve communication, collaboration, and support among students, teachers, scientist mentors, PlantingScience liaisons, and the PlantingScience staff. The numbers on the figure correlate with the explanatory statements in the information below the figure.

1. Teachers are important guides for students throughout the PlantingScience modules.
2. Students interact with scientist mentors through the PlantingScience online platform. Students can ask their mentors about their interests and career choices and ask questions and get feedback on their PlantingScience investigations.
3. Teachers and scientist mentors communicate about the classroom environment and scheduling to ensure that mentors are available at the appropriate times and have information about their students' classroom environment.
4. PlantingScience liaisons are available to assist scientist mentors with any questions they may have or provide guidance for how to respond to certain questions from students. PlantingScience liaisons also monitor communications to ensure that scientist mentors are responding to students in a timely fashion.
5. Teachers may reach out to PlantingScience liaisons with any questions they have about the program or to get additional assistance if a scientist mentor is not available.
6. PlantingScience liaisons may respond to student inquiries either to supplement information from a scientist mentor or to fill in if a mentor is unavailable temporarily.
7. PlantingScience staff monitors communications on the website and are available to help teachers, scientist mentors, and PlantingScience liaisons if any issues arise.

Table 3. An overview of the student activities in the PlantingScience Power of Sunlight module. Power of Sunlight resources available at https://plantingscience.org/posinformation.

Activity Sequence	Investigation	Purpose of Activity	Interactions with Mentors
1. Thought investigations	Change in mass of radish seedlings in different light and water conditions Classic experiment (van Helmont) to determine whether mass of plant comes from the soil	Students engage in thought investigations that set up discrepant events to draw out current thinking and reveal potentially inaccurate conceptions. Students will revisit these thought investigations later in the module and use information gained in later lessons to explain these seemingly discrepant events.	Teams begin introducing themselves to mentors. Students often ask their mentors about their career choices and interests.
2. Guided investigation	Spinach leaf disk experiment	Students work through a guided investigation to learn about photosynthesis and experimental design. They focus on the relationship between evidence and explanation when they analyze their results.	Students can share the results of their investigations with mentors.
3. Semi-guided investigation	Modifying spinach leaf disk investigation for different conditions	Students gain experience in experimental design by modifying the leaf disk assay to investigate additional requirements for photosynthesis and cellular respiration.	Students can get feedback on their data analysis and explanations.
4. Student-initiated investigation	Independent small-team investigations Students work in teams to plan, conduct, and analyze an investigation to answer a scientific question of their own choosing.	Student teams plan, conduct, and analyze an investigation to answer a scientific question of their own choosing about photosynthesis or cellular respiration. They experience scientific research in an authentic way as they conduct their investigations.	Teams interact with mentors to get feedback on their research question, their experimental design, their data, and conclusions of their investigation.

work in this module. See Table 3 for an overview of the Power of Sunlight student activities.

The second component of the PlantingScience STSP involves online mentoring by professional scientists. Throughout the module, students communicate asynchronously with scientist mentors through the PlantingScience website. Each teacher collaborates with a PlantingScience liaison who helps monitor and facilitate student–mentor conversations and enhances communication between the teacher and mentors. Teachers and liaisons are provided with a list of available scientist mentors. Liaisons and teachers collaboratively consider what mentor characteristics are most appropriate for the teacher's class. Teachers or liaisons can select mentors based on information shared on the mentor's profile (e.g., language proficiency, demographic similarities to students, location, or local research connection, and so forth). Once invited, mentors can accept or decline an invitation. Accepted mentors are then matched to a particular student team by the teacher or liaison. Each team of 3–5 students has their own mentor, so a class of 30 students will work with 6–10 scientist mentors. Students share their ideas, results, and questions about their investigations with their mentor. They can also ask about their mentor's career and life as a scientist. The far right column of Table 3 describes how interactions with mentors align with the activity sequence of the Power of Sunlight curriculum.

A key aspect of the PlantingScience program is that students, teachers, mentors, and PlantingScience liaisons work together. Figure 1 presents a summary of the communication and interaction between roles.

Collaborative Teacher/PlantingScience Liaison Professional Learning

The final component of the PlantingScience STSP is collaborative PL for teachers and liaisons. Teacher skill in implementation is a critical component of STSPs as described by Tinker (1997). The PL component provided in this study served to encourage collaboration between teachers and PlantingScience liaisons and to deepen their understanding of the Power of Sunlight module. Teachers assigned to the treatment condition attended a PL workshop held at BSCS Science Learning headquarters in Colorado Springs, CO, prior to teaching the Power of Sunlight module to their students. PlantingScience liaisons also attended the workshop. The workshop included approximately 40 hours of contact time spread over six days. During the workshop, participants experienced the Power of Sunlight activities much as students would in the classroom (see Table 1). Through the PL experience, teachers prepared to implement the module in the classroom more effectively. Liaisons also learned strategies for providing high-quality feedback to students and mentors. Involving PlantingScience liaisons is a practical approach to address the quality, consistency, and frequency of scientist–student interactions (Desy et al., 2018; Scogin & Stuessy, 2015; Peterson, 2012). Previous studies found that the different environments and cultures in which teachers and scientists usually work can create challenges within STSPs (Carr, 2002; Houseal et al., 2014). The PL experience in this study provided an opportunity for teachers and scientists to work collaboratively to better understand and value the knowledge and skills brought by each group and how those skills can be leveraged to improve the student experience. This experience enabled teachers and PlantingScience liaisons to better anticipate likely problems and questions that arise in the classroom. In addition to sessions related to science content, the workshop included sessions related to pedagogical strategies designed to reveal and challenge student thinking. Teachers and liaisons also participated in activities to familiarize them with the PlantingScience online communication tools and discussed examples of dialog between students, mentors, teachers, and liaisons from previous projects.

The control condition (BaU)

Teachers assigned to the control condition were asked to teach the topics of photosynthesis and cellular respiration to their students using their usual materials and instructional approaches, as well as in a timeframe similar to the duration of the Power of Sunlight module.

Measures

Students in both treatment conditions completed pretest and posttest assessments (Taylor et al., 2022). The pretest and posttest forms were identical. The assessments were developed by the research team and the full content of both measures are published in a previous article (Taylor et al., 2022). They are also available online at https://plantingscience.org/about/testquestions.

Outcome measure: Science achievement

The science achievement measure included 26 multiple-choice items covering photosynthesis and cellular respiration, including ones designed to reveal common student preconceptions or misconceptions related to this topic. To ensure that the achievement test was not over-aligned to the treatment condition, teachers in both treatment conditions received targeted learning goals prior to instruction.

Outcome measure: Students' attitudes toward scientists

The student attitudes toward scientists measure included 10 Likert-scale items covering students' attitudes toward scientists.

Demographic and developmental indicators

Students self-reported their inclusion in a set of demographic and developmental groups. These included students' gender, English non-native language status, free- or reduced-price lunch status, race, and ethnicity. Students also reported their grade level. Students were not required to respond to questions about demographics.

Analysis Approach

Multilevel modeling

Because we were interested in finding out how the PlantingScience Power of Sunlight experience affected both science achievement and attitudes about scientists, we ran separate models to measure each of these outcomes independently. In each model, students' characteristics and outcome scores (achievement or attitudes) were nested within teachers. Consequently, a multilevel (two-level) model was run that appropriately accounted for this hierarchical structure of the data. Specifically, students' outcomes at level 1 were modeled as a function of student-level predictors such as the pretest score on the outcome measure, sex, grade level, English language learner status, and free or reduced-price lunch status. In addition, a series of indicators for student race/ethnicity were included Asian, African American, American Indian/Alaska Native, Hawaiian/Pacific Islander, Hispanic, or Other race. In these models, white students were the reference group so all coefficients for race variables represent comparisons of outcomes between the indicator group of students and white students. Level 2 (teacher level) variables included these student-level indicators aggregated to the teacher level (e.g., mean grade level, percentage of a teacher's students in each indicator category) and the binary treatment/no treatment indicator.

Effect sizes for impacts

Effect sizes corresponding to the treatment effects estimated using the multilevel models were computed following the *What Works Clearinghouse Procedures and Standards Handbook 4.0* (Institute of Education Sciences [IES], 2019). That is, the effect size numerator was the treatment effect estimate from the multilevel model (i.e., the covariate-adjusted mean difference) and the denominator was the pooled student-level standard deviation (SD). The effect size estimate was then adjusted for small sample bias as in Hedges (1981), resulting in a Hedges' *g* estimate.

○ Results

After attrition, the study sample included 64 teachers (27 treatment, 37 control). The final analytic sample included students for whom we had complete data on outcome measures (pre- and post-intervention) as well as all demographic indicators (514 treatment, 1021 control).

Multilevel modeling results for effects on student achievement and attitudes are in Tables 4 and 5, respectively. Note the positive and statistically significant treatment effects, bolded in both tables.

These treatment effects indicate that students in the treatment group, on average, outperformed their counterparts in the control group on measures of achievement and attitudes about scientists. Table 6 provides descriptive statistics for both outcome measures on the analytic sample of students. The adjusted means in Table 6 are based on the posttests. They are derived from the treatment effects bolded in the regression results in Tables 4 and 5, where the coefficient for each treatment indicator is interpreted as an adjusted mean difference in outcomes across treatment conditions. More specifically, the adjusted means represent the average posttest scores, by treatment condition, estimated as if the two groups were completely equivalent on pretest and group characteristics.

The core finding of this research was that implementing the Power of Sunlight module in combination with high-quality PL for teachers and PlantingScience liaisons resulted in positive and statistically significant effects. Once the regression coefficients for the treatment indicator (see Tables 4 and 5) are standardized as effect sizes (i.e., Hedges'g; Hedges, 1981), they correspond to $g = 0.284$ for achievement and 0.280 for attitudes, indicating that the Power of Sunlight group outperformed the control group by approximately 0.28 SDs, a significant difference, for both outcomes.

As an additional metric for expressing the size of the program impact, we use the *What Works Clearinghouse (WWC) Improvement Index*. The WWC Improvement Index is the expected change in percentile rank for an average comparison group student after receiving the intervention (IES, 2022). When calculated for the student achievement data in this study, we observed an improvement index of +11. Therefore, on average, a student in the comparison group who scores at the 50th percentile would be expected to have scored at the 61st percentile if they had received the intervention.

Table 4. Impact on student achievement.

Fixed Effect	Coefficient	Standard Error	*P*
Intercept	46.798	0.588	<0.001
School mean pretest achievement	0.122	0.174	0.487
Treatment effect	**3.121**	**1.260**	**0.017**
Percent female	0.673	4.027	0.868
Mean grade level	1.507	0.830	0.075
Percent Asian	3.307	7.358	0.655
Percent Black or African American	−7.540	6.822	0.274
Percent American Indian or Alaska Native	−24.905	8.816	0.007
Percent Hawaiian or Other Pacific Islander	57.074	19.990	0.006
Percent Hispanic or Latino/Latina	−4.342	6.029	0.475
Percent White	−2.960	7.089	0.678
Percent Other race	−25.606	17.279	0.145
Percent English language learner	−3.497	7.589	0.647
Percent free or reduced-price lunch	5.677	3.438	0.105
Female	−1.010	0.504	0.045
Grade level	0.517	0.445	0.246
Asian	1.295	0.945	0.171
Black or African American	−2.157	1.015	0.034
American Indian or Alaska Native	−2.425	1.107	0.029
Hawaiian or Other Pacific Islander	−2.935	2.039	0.150
Hispanic or Latino/Latina	−1.366	0.773	0.078
Other race	−3.971	1.881	0.035
English language learner	−0.607	0.703	0.388
Free or reduced-price lunch	−1.605	0.649	0.013
Pretest achievement	0.247	0.034	<0.001

Table 5. Impact on student attitudes toward scientists.

Fixed Effect	Coefficient	Standard Error	*P*
Intercept	50.136	0.348	<0.001
School mean pretest attitudes	0.343	0.208	0.106
Treatment effect	**2.351**	**0.739**	**0.003**
Percent female	−2.528	2.322	0.282
Mean grade level	−0.265	0.535	0.623
Percent Asian	2.691	4.414	0.545
Percent Black or African American	2.609	4.085	0.526
Percent American Indian or Alaska Native	−26.751	5.263	<0.001
Percent Hawaiian or Other Pacific Islander	24.613	11.875	0.043
Percent Hispanic or Latino/Latina	5.808	3.633	0.116
Percent White	10.511	4.192	0.015
Percent Other race	−2.849	10.570	0.789
Percent English language learner	3.925	4.724	0.410
Percent free or reduced-price lunch	3.712	2.043	0.075
Female	0.852	0.414	0.040

Table 5. *Continued*

Grade level	0.320	0.365	0.382
Asian	0.968	0.775	0.212
Black or African American	1.773	0.832	0.033
American Indian or Alaska Native	−1.751	0.908	0.054
Hawaiian or Other Pacific Islander	−0.296	1.673	0.860
Hispanic or Latino/Latina	−0.155	0.634	0.807
Other race	−0.513	1.543	0.739
English language learner	0.527	0.576	0.360
Free or reduced-price lunch	−0.913	0.532	0.086
Pretest attitudes	0.423	0.033	<0.001

Table 6. Adjusted and unadjusted means by treatment condition: Achievement and attitudes.

	Treatment				Control			
Outcome	***n***	**SD**	**Mean**	**Adj. Mean**	***n***	**SD**	**Mean**	**Adj. Mean**
Achievement	514	10.030	48.441	48.115	1021	11.448	48.002	44.994
Attitudes	514	6.881	50.903	51.128	1021	9.055	50.268	48.778

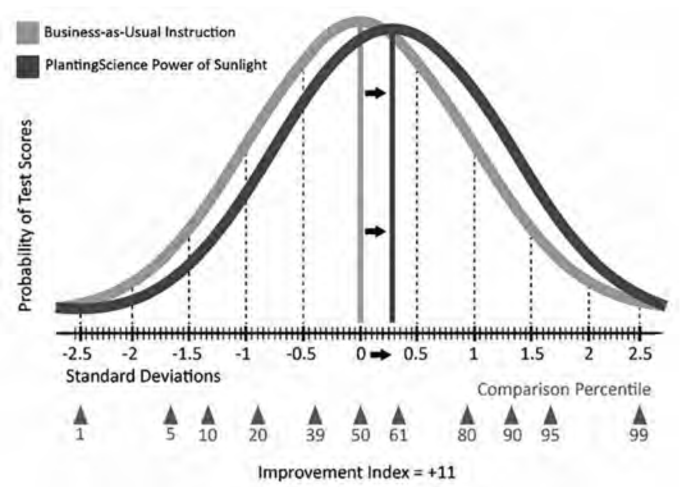

Figure 2. Improvement index for the effects of the Power of Sunlight module.

The Improvement Index score for student attitudes about scientists was also an increase of 11 percentile points for students receiving the intervention (Figure 2).

○ Discussion

This study not only provides needed rigorous quantitative evidence about the efficacy of the PlantingScience program but also adds to the limited information in the literature about the impact of STSP programs on student outcomes related to both science content knowledge and attitudes about scientists. Before starting the research study, teachers in both groups self-reported their frequency of using common teaching practices, such as small-group discussion, hands-on activities, textbook readings, developing explanations, and so forth in their classrooms (Taylor et al., 2022). These self-reports showed the frequency of these practices was similar in both groups. This suggests that the improvements in student outcomes are more likely attributable to the Power of Sunlight module implementation than to differences in the classroom practices themselves. Furthermore, these effects were observed using a study sample that was largely representative of the population of U.S. high schools, increasing confidence that the observed effects are generalizable to contexts that mirror the demographic profile of the nation's students at large.

There are a small number of studies to which the effects of the PlantingScience Power of Sunlight module can justifiably be compared. One study, "Students, Teachers, and Rangers & Research Scientists: Investigating Earth Systems at Mammoth Hot Springs" (STaRRS; Houseal et al., 2014), is perhaps the most similar in design. That study used a quasi-experimental design (although not a randomized trial) to look at the effects of an STSP program on student outcomes. Houseal et al. (2014) found statistically significant effects of the STSP on both middle school students' attitudes toward science and their science content knowledge. We used the descriptive statistics reported in the STaRRS study to estimate an effect size for science content (g = 0.77 SD). It was not possible to do the same for the attitudes outcome. Another quasi-experimental study conducted in Taiwan also found positive outcomes for students who participated in an STSP program (Shein & Tsai, 2015). Although that study was quite different in format than the current study and involved only a small number of students, the results showed that students had moderate gains in science content knowledge and larger gains in attitudes about science.

The PlantingScience format presents several advantages over other STSPs. In the Power of Sunlight module, PlantingScience liaisons and teachers interacted face-to-face during the PL workshop and online thereafter. Students had opportunities to communicate with their mentors online throughout the Power of Sunlight investigations in their classrooms. An important feature of PlantingScience is that all students in the teacher's class have the opportunity to interact with scientist mentors. This is unlike many STSPs and SSPs that are available only to a limited number of students who already have a high interest or achievement level in science, who can participate in extracurricular programs, or who can travel to the scientist's location. Furthermore, teachers can select PlantingScience mentors that seem to be a good fit for their students based on mentor profiles. The PlantingScience mentor gallery includes over 700 plant scientists of various ages, identities, and language fluencies. Their profiles also include information about their outside interests and career pathways. Interacting with mentors with diverse backgrounds can help students learn that successful scientists do not all fit common stereotypes (Schinske et al., 2015; Shin et al., 2016). Perceived similarities between a mentor and mentee can also positively affect the mentee's perception of their mentoring relationship (Hernández et al., 2012). Finally, an online platform alleviates one of the challenges identified for STSPs – the time and travel required for the participating scientists (Houseal et al., 2014). In the PlantingScience model, scientist mentors can communicate from their home institution or even from their research locations. This not only makes it more feasible for scientists to fit mentoring into their schedules but also to reach students who are in distant or rural locations far from scientists' workplaces.

In this study, we observed a significant positive effect of the Power of Sunlight module on student attitudes toward scientists. This effect is important because students' attitudes about science and scientists have been shown to impact and be impacted by the science instruction they receive, and may impact students' formation of a science identity, or an individual's belief that they could see themselves as a scientist. This may be especially true for those underrepresented in science (Brickhouse & Potter, 2001; Farland-Smith, 2009; Jones et al., 2000; Osborne et al., 2003; Schinske et al., 2015; Trujillo & Tanner, 2014; Wyer et al., 2010).

Unrealistic stereotypes about who scientists are and what they do abound and persist unless challenged (Mead & Metraux, 1957; Welch & Huffman, 2011). This stereotypic thinking can influence motivation, behavior, academic performance, and cognitive processes, which may lead to under-identification or participation in communities of practice (Hilton & von Hippel, 1996). The opportunity for students to communicate directly with scientist mentors is a key component of the PlantingScience experience. This communication ranges from discussions of their research investigations to questions about how the mentor pursued their career in science. This direct interaction with a scientist is one strategy to build the student's science identity. Students benefit from knowing that there are "people like them" who are career scientists. Shin et al. (2016) found that exposing students to online biographies of scientists who challenged the common stereotypes of scientists as "naturally high achieving in science" or White males had positive effects on both science, technology, engineering, and mathematics (STEM) and non-STEM students' interest in STEM. Further, Woods-Townsend et al. (2015) found that even very short face-to-face discussions with scientists helped students move from viewing scientists as nerdy and boring to approachable and normal. Participation in PlantingScience may be an especially valuable experience because science identity may be established by the time a person reaches the mid-teen years – the age at which most students would participate in PlantingScience. Tai et al. (2006) found that eighth grade students who expected to have a career in science were much more likely to earn a college degree in a science field than were students who did not expect a career in science.

Tinker identified key factors for the success of STSPs, including the skill of the teacher, the availability of related curriculum materials with explicit student learning goals, and the opportunities for students to actively participate in research. The Power of Sunlight PL that teachers participated in during the research project and the Power of Sunlight curriculum materials fulfill the first two criteria, and the third criteria is met with the culminating experience in the Power of Sunlight module. In that experience, students design and conduct their own research investigations starting with the development of testable questions and ending with the analysis of experimental results and the communication of their findings to others. Research shows that positive experiences with authentic science experiences can improve students' research self-efficacy, a key factor in the development of science identity (Adedokun et al., 2013). Importantly, the Power of Sunlight curriculum provides these key features that are critical for the success of this type of STSP.

Teacher development is one area specified in the *Framework for K–12 Science Education* for effective science education (National Research Council, 2012). Previous case-study research with PlantingScience teachers highlighted the finesse required to co-mentor students through their investigations (LeBlanc et al., 2017). A goal for the PL was to bring scientist mentors and high school teachers together so they could experience the Power of Sunlight materials jointly, thereby being better prepared to enhance the students' learning experiences. Caton et al. (2010) found that the collaboration between scientists and teachers can have beneficial outcomes when both groups can explore inquiry-based curriculum together and when both groups are viewed as equal partners. This idea of an equal partnership between teachers and PlantingScience liaisons was an explicit part of the planning for the PL workshop. Not only would this shared experience enhance the teachers' skills with the module but would also help prepare mentors for what they would experience with their student teams. This collaboration during the PL also helped the PlantingScience liaisons and the high school teachers develop a better expectation for how the students would respond to the science content in the Power of Sunlight module. PlantingScience liaisons learned more from the teachers about what high school students would find either straightforward or challenging about the Power of Sunlight concepts. The teachers learned more from the PlantingScience liaisons about the science content, data analysis, and the approach that a scientist would take learning these concepts. The PlantingScience liaisons also fulfill a key role by serving as third-party intermediaries who speak the language of both teachers and mentors to facilitate communication and assist in problem-solving as necessary (Houseal et al., 2014).

Some limitations of this study include differences in the way the Power of Sunlight activities were delivered in different classrooms. Some teachers experienced delays in teaching the module activities that meant the activities needed to be condensed into a shorter time period. In other cases, it took longer than expected to recruit enough scientists to work with student teams, which meant that teams had fewer opportunities to build relationships with scientists. Participating teachers were also using the Power of Sunlight module for the first time. Trying something new in the classroom can be challenging for teachers when they don't yet have the experience and confidence they would gain over time (Fullan, 2001). While the population of the schools in the study sample was largely representative of the population of U.S. high schools, students in classes that participated in the study may not have mirrored their school population exactly. Teachers self-selected to participate in this research with their students and may have characteristics (motivation, qualifications, etc.) different from a sample of teachers assigned to participate.

This rigorous study adds to the literature to show that multifaceted STSPs can improve student outcomes. The study does not show which aspects of the program contributed more or less to the student gains. Future studies could be designed to determine how the various components (e.g., curriculum, teacher development, and scientist mentoring) influence the effects on student outcomes. Another direction for further research is to investigate in more detail how STSPs work for particular subgroups of students, especially those from underserved populations. Supplementing quantitative data obtained in studies like this one with qualitative research exploring participant experiences will allow further investigation of why outcomes differ between groups. How are particular components of STSP interventions received by particular participants, and how does that shape outcomes for them? Hmelo-Silver et al. (2007) call for more studies that take the next step; after answering if a particular program works to achieve outcomes, we need to know under which conditions it works, and for whom it works.

○ Acknowledgments

The authors thank Lisa Carey, Senior Research Associate at BSCS Science Learning, for providing valuable assistance throughout the project including recruiting teachers, working with school districts to obtain approvals for conducting research, and with cleaning and organizing data. This material is based upon work supported by the National Science Foundation under DRL Grant 1502892. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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