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Identifying the Factors Leading to Success: How an Innovative Science Curriculum Cultivates Student Motivation

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Abstract *PlantingScience* is an award-winning program recognized for its innovation and use of computer-supported scientist mentoring. Science learners work on inquiry-based experiments in their classrooms and communicate asynchronously with practicing plant scientist-mentors about the projects. The purpose of this study was to identify specific factors contributing to the program's effectiveness in engaging students. Using multiple data sources, grounded theory (Strauss and Corbin in Basics of qualitative research. Sage, Newbury Park, 1990) was used to develop a conceptual model identifying the central phenomenon, causal conditions, intervening conditions, strategies, contexts, and student outcomes of the project. Student motivation was determined to be the central phenomenon explaining the success of the program, with student empowerment, online mentor interaction, and authenticity of the scientific experiences serving as causal conditions. Teachers contributed to student motivation by giving students more freedom, challenging students to take projects deeper, encouraging, and scaffolding. Scientists contributed to student motivation by providing explanations, asking questions, encouraging, and offering themselves as partners in the inquiry process. Several positive student outcomes of the program were uncovered and included increased positivity, greater willingness to take projects deeper, better understanding of scientific concepts, and greater commitments to collaboration. The findings of this study provide relevant information on how to develop curriculum, use technology, and train practitioners and mentors to utilize strategies and actions that improve learners' motivation to engage in authentic science in the classroom.

Keywords Grounded theory · Science education · Mentoring · Motivation · Technology

Introduction

PlantingScience (PS), developed in 2005 by the Botanical Society of America (BSA), is a prestigious Science Prize for Online Resources in Education (SPORE) award-winning program recognized by the American Association for the Advancement of Science (AAAS) for its complex design engaging classroom teachers, students, and scientist-mentors in an innovative, computer-supported science-learning environment (Hemingway et al. 2011). Used internationally by over 12,000 students at the time of this study, PS provided advanced technology tools to mix scientific inquiry, classroom instruction, and online mentoring by practicing scientists and advanced science graduate students. Science learners, working in small teams of two to four students, designed and carried out 3- to 10-week long inquiry-based experiments related to plant biology. Students communicated asynchronously about their scientific inquiries with practicing plant scientist-mentors in an online forum open to the public. Scientist-mentors read students' posts and provided their own comments and questions to enhance the quality of the students' inquiry experiences. Specific topics for the inquiry units included

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seed germination (i.e., *The Wonder of Seeds*), photosynthesis (i.e., *The Power of Sunlight*), and sexual reproduction and alternation of generations in ferns (i.e., *C-Ferns in the Open*), among several others.

BSA scientists created the PS program in response to a challenge issued by Bruce Alberts, former president of the National Academy of Sciences (NAS). While president of the NAS, Alberts delivered the keynote address at the 2003 annual meeting of the Botanical Society of America and urged BSA scientists to bridge the gap between scientists and science classrooms (Musante 2006). Inspired by the challenge, the BSA developed PS with three overarching objectives: (1) provide opportunities for scientific inquiry experiences, (2) integrate plants into the science curriculum, and (3) facilitate online mentoring between scientists and students (Hemingway 2008).

While other scientist partnership programs have been used in K-12 educational settings (e.g., Brown et al. 2014), PS was unique in that scientists partnered directly with students who were working within the confines of their own classrooms. Students did not travel to scientists' laboratories or meet scientists in the field, and scientists did not meet students face-to-face in the schools. Furthermore, the partnerships were between scientists and students, not scientists and teachers as has often been the case in other scientist partnership programs (Brown et al. 2014; Falloon 2013). While scientists developed PS curricular modules and K-12 teachers helped adapt the modules for classroom use (Musante 2006), the key role of the mentoring scientists in the PS project was more closely related to a science apprenticeship as defined by Bell et al. (2003). According to Bell et al. (2003), science apprenticeships are characterized by scientists serving as mentors who provide guidance to students about the scientific research process and provide assistance when challenges occur during the investigations.

In PS, students in the classrooms (with direction from their teachers) designed their own research questions within the boundaries of the existing curricular modules, and scientist-mentors voluntarily partnered with these students to refine the research questions, develop appropriate methodology to answer the questions, make decisions about reliable evidence, and reach credible conclusions. Again, this type of partnership and setup was fundamentally different from other scientist partnership models (e.g., Brown et al. 2014; Falloon 2013) as PS students worked directly with scientists, were restricted to their own classrooms, and had some autonomy to choose their projects within existing curricular modules as opposed to working on scientists' extant projects.

In addition to the classroom component, the BSA and a large public university conducted summer teacher training workshops from 2008–2011. Scientists led these professional development workshops with the goal of modeling inquiry-based approaches for K-12 teachers. The program became overwhelmingly popular as evidenced by the increase in the number of participants over the life of the program (see "Methodology" section). As a result of the popularity and the award issued by AAAS, the word "successful" became synonymous with PS.

The current study emerged from a desire to determine what made and continues to make PS popular (i.e., successful) from the perspectives of its participants: teachers, scientist-mentors, and students. Researchers divorced from the program's development decided an inductive analysis technique (like grounded theory) would provide the best method for determining which parts of the PS program were responsible for the positive reactions among participants. PS was developed to mimic real scientific discovery, but which parts of that process (if any) were important from participants' viewpoints? Few publications exist (e.g., Scogin and Stuessy 2015) using PS data, so this study helps move the conversation from anecdotes to evidence-based reasoning. The purpose of this study was to identify specific factors contributing to the program's popularity and success in engaging students in scientific inquiry.

Background

Programs uniting students with scientists in research apprenticeships have become increasingly popular, and some programs have produced positive student outcomes (Sadler et al. 2010). Programs of this nature are not new, as students have attended summer camps, weekend research events, and after-school science mentoring programs at local colleges and universities for many years (e.g., Yale Science Outreach, Mentoring for Science at Harvard). However, many of the programs bringing scientists and students together are relatively short-lived and do not support the contact time necessary for building strong partnerships (Pekar and Dolan 2012). In other words, many student-scientist partnerships may not provide the needed context for scientists to impact students in tangible ways. When done correctly, however, putting students and professionals (i.e., scientists) together in mentoring relationships contributes to students' self-efficacy (Mullen 2011) by promoting active learning guided by experience (Pajares 2008).

One example program developed in the 1990s was an online mentoring project linking a geology graduate student with students studying earthquakes in an Earth Science class (O'Neill et al. 1996). The students communicated with their mentor via e-mail over a 7-week period. The Earth Science class mentoring experience was part of the Collaborative Visualization (CoVis) project at Northwestern University in

Chicago, Illinois. Developers designed the project to "understand how science education could take broad advantage of [technological] capabilities, providing motivating experiences for students and teachers with contemporary science tools and topics" (Pea 1993, p. 61). Discontinued in 1998, the CoVis project explored remote collaborations between high school students involved in inquiry-based activities and atmospheric and environmental scientists and graduate students.

Since the discontinuation of CoVis, some researchers like Bryan et al. (2011) have called for the recruitment of "women and men who are in science-related careers in the community to participate in school science activities and serve as science role models" (p. 1062). According to these authors, mentors can share experiences, discuss responsibilities, relay challenges, and generally build relationships with students. Furthermore, programs uniting students and scientists in partnerships can help break down some of the incorrect stereotypical beliefs students have about scientists (Mead and Meatraux 1957; Welch and Huffman 2011).

PlantingScience provides a contemporary glimpse at what is possible when professional scientists and classroom learners unite in online mentoring partnerships. The program has been both fast-growing and resilient (more so than CoVis), expanding from a vision of the BSA to a program with multiple organizational partners and tremendous student participation numbers. Similar to CoVis, PS partners practicing scientists or graduate students with classroom science learners. Though similar in principle, the two programs differ in many ways. PS, unlike CoVis, provides curricular materials and activities for its participants. Additionally, PS allows only asynchronous communication between scientist-mentors and classroom learners, whereas CoVis used both synchronous and asynchronous methods.

Anecdotal evidence suggested the relationships developed between students and the scientists in the asynchronous, text-based conversations were of paramount importance to the success of PS. According to the *Science* article touting PS as a successful SPORE winning program (Hemingway et al. 2011), "Talking online with a scientist is exciting and motivating to students. Teachers commonly relate that their students develop a new level of confidence and responsibility toward their experiments" (p. 1536). In the current study, the goal was to tease out the conditions and strategies contributing to the widespread use of the program through the use of grounded theory.

The desire to learn more about this innovative program through analysis of rich data gathered from the field and directly from participants made the selection of qualitative methods appropriate for this study. This study used ecologically valid methods in order to focus on "naturally occurring, ordinary events in natural settings" (Miles et al. 2014, p. 11). Since classroom environments are extremely complex, rarely if ever following a one-size-fits all "Betty Crocker" pattern (Eisner 1985), investigating them presents an imposing challenge. "The evaluative task in this situation is not one of applying a common standard to the products produced but one of reflecting upon what has been produced in order to reveal its uniqueness and significance" (Eisner 1985, p. 55). PS is a complex program blending traditional classroom interaction with progressive methods such as inquiry-based learning, online mentoring, and scientist-student partnerships. In many cases, complex dynamics lend themselves better to qualitative research because of the explanatory power these types of methods offer (Meyer and Turner 2002).

Methodology

Population and Sample Descriptions

Participation in PS has skyrocketed since its launch in 2005. For example, student participation grew from under 200 students (41 student-teams) in 2005 to a peak of over 1600 students (437 student-teams) in 2011. Similarly, the number of scientist-mentors grew from 7 in 2005 to a peak of 225 in the fall of 2011. In regard to teacher participants, a 2013 report indicated 129 teachers from 37 different states had been involved in PS since its inception. Of these, approximately 50 attended the summer workshops conducted from 2008–2011. This study includes direct contributions from 7 teachers, 34 scientists, and 27 student-teams. Selection criteria for each group of participants are discussed in the following sections.

Data Sources

Four data sources were consulted in this study (Table 1). They included one stakeholders' focus group held in the Midwest; two high school classroom observations (one in the western US and one in the Midwest US) and follow-up interviews with the teachers observed; and 17 online scientist-student dialogues associated with "exemplary" projects identified by the BSA.

Focus Group

A stakeholders' focus group meeting occurred over a day-and-a-half period and included 19 participants (i.e., scientists, teachers, PS program developers, and education researchers). Employees of the BSA selected participant teachers and scientists based on their experience and expertise in the PS learning environment. Assembling an

Table 1 Data sources and characteristics

Context	Source/informants	Data
Focus group	Scientists, teachers, and science educators engaged in a 1–1/2 day stakeholders' meeting ($n = 19$)	Audio-recorded discussions, transcripts, field notes
High school classrooms	Student-teams from two different classrooms engaged in PS ($n = 10$)	Video-recorded classrooms; Scientists-students coded dialogues
High school teacher interviews	Two teachers observed in two different PS classrooms ($n = 2$)	Audio-recorded discussions, transcripts, field notes
Online dialogues	Asynchronous dialogues between scientist-mentors and student-teams from projects identified as "exemplary" by the BSA ($n = 17$)	Scientists-students coded dialogues

eclectic group of teachers and scientist-mentors for a focus group presented logistical challenges. As a result, the focus group was held in conjunction with a national botany conference. The number of participants in the group was significantly larger than is customary for a focus group (Krueger and Casey 2009). However, in a manner consistent with a Town Hall Focus Group (Zuckerman-Parker and Shank 2008), smaller groups were formed during the session to facilitate intimate discussions. The discussion environment was open and relaxed, providing everyone with comfort to have passionate yet productive exchanges about the PS program.

High School Classrooms

Two teachers were purposively selected for observations because of their experience and expertise in PS delivery. Both teachers attended more than one summer training workshop, and they both completed multiple cycles of PS with different groups of students through the years. The two classroom observations yielded field notes and video recordings of four lessons over 4 days engaging students in inquiry activities associated with *The Wonder of Seeds*. After classroom observations, researchers conducted exit interviews with each teacher (i.e., Dan from the Midwest and Kelly from the western US; pseudonyms) while taking notes and audio recording the conversations for transcription.

Online Dialogues

The dialogues from the 10 student-teams associated with the two classroom observations served as data sources. When completing the grounded theory analysis, an additional 17 exemplary online dialogues were purposively selected and added to reach theoretical saturation (Strauss and Corbin 1990). In all, 27 student-team/scientist-mentor dialogues were included as data sources in this study.

Analytical Strategies

Data from the focus group included records of participants' comments that may have been (a) transcribed word-for-word as they were being spoken, (b) recorded as heard from audio-recorded conversations, or (c) paraphrased as phrases or sentences drafted by the researcher to describe or recollect a particular event. Using a basic grounded theory methodology (Glaser and Strauss 1967), the research team inductively determined the major themes of the focus group discussions. Individual researchers segmented their transcribed field notes into smaller units, or "raw data bits" (Lincoln and Guba 1985), representing discrete events related to the same content. Individual researchers used constant comparison to code and cluster their data bits to yield categories (Goetz and LeCompte 1981).

Time and time again, teachers and scientists made reference to students' interests in science, plants, and/or experimentation skyrocketing after PS engagement. Therefore, student motivation was established as the central phenomenon, and the complementary categories were subsequently related to motivation (Scogin et al. 2013).

Theoretical Sampling

While the initial use of grounded theory methodology revealed a central phenomenon (i.e., student motivation) and several contributing categories, the original grounded theory lacked process. Strauss and Corbin (1990) defined process as "the linking of action/interactional sequences" (p. 143). In order to gain additional perspective, the original study was expanded to include other data streams as a form of theoretical sampling. As stated by Strauss and Corbin (1990), theoretical sampling is the inclusion of additional data in an effort to increase understanding of the properties and dimensions of categories as well as verify the relationships between categories. The result was a more comprehensive and robust framework describing and outlining the reasons why PS motivated students and how the other actors (i.e., teachers and scientist-mentors) facilitated motivation under differing contexts and conditions.

The new samples included data from classroom observations, interviews with the teachers of those classrooms, the scientist-student dialogues generated from 10 student-teams in two classrooms, and the online dialogues of 17 exemplary projects as identified by the BSA (Table 1). Open, axial, and selective coding (Strauss and Corbin 1990) were used to systematically integrate new data and reconstruct the grounded theory. During this process, open codes were used to fracture the data, identify categories, and ascertain properties and dimensions. Axial coding followed, with identification of the *central phenomenon*, *causal conditions*, *intervening conditions*, *strategies*, *contexts*, and *outcomes* of successful PS implementation. Finally, selective coding was used to systematically relate the categories and conditions together as per Strauss and Corbin's (1990) paradigm model, thereby creating a more comprehensive, inductive conceptual framework.

The paradigm model provided a framework to ascertain relationships between the following categories: causal conditions, central phenomenon (core category), actions/strategies, intervening conditions, and consequences. Using all data streams, data were collapsed to form new emerging categories, verify relationships between categories, and establish and validate the properties and dimensions of all categories. Ultimately, a conceptual framework emerged from the process to explain the factors contributing to student motivation and engagement.

Analytical Rigor

Throughout this study, the following strategies recommended by Wolcott (1994) were used to preserve analytical rigor: (1) Classroom observations were conducted in an inconspicuous fashion. Researchers unobtrusively video recorded, took field notes of observations, and analyzed online communications. (2) The research team archived all collected data including video and audio recordings, transcribed information, and field notes. (3) The research team prepared reports to the BSA and the National Science Foundation (NSF) and authored conference presentations at all stages of the research process, thereby establishing a chain of evidence representative of Wolcott's "early writing." (4) All members of the research team made significant efforts to report results candidly, accurately, and with feedback from other researchers involved in various capacities with the project.

In addition to the considerations offered by Wolcott (1994), Johnson (1997) provided additional strategies for rigorous qualitative analysis. Johnson suggested extended fieldwork, low inference descriptors, triangulation (including data, methods, and investigator), and peer review. These strategies were utilized in the following manners: (1) Data were collected from extended fieldwork including PS classroom observations, teacher interviews, focus group discussions, and scientist-student asynchronous dialogues. (2) Data were collected in various ways, including direct observations, personal interviews, focus group conversations, and textual dialogues. (3) Researchers from both inside and outside the project served as peer reviewers at various stages of the process.

Findings

The *Science* article, SPORE award, and popularity of the PS program at large provided anecdotal evidence that PS was a successful program. In the current study, grounded theory (Strauss and Corbin 1990) was used to identify evidence-based factors contributing to successful PS experiences. Table 2 details the raw categories, properties, and dimensions that emerged from this analysis.

The Central Phenomenon: Student Motivation and Engagement in Science

In this study, data collected from multiple sources indicated PS was successful because of its tendency to motivate and engage students. Many teachers who used PS reported similar outcomes to this teacher who shared, "The level of engagement in the class is high. I have a few in the class that are not engaged, but it's not for very long." Figure 1 illustrates the theoretical framework (per Strauss and Corbin 1990) generated in this study to explain the central phenomenon of student motivation and engagement. Three causal conditions contributed to student motivation, and both teachers and scientist-mentors used various strategies and actions to facilitate motivation. These strategies and actions were influenced by changing contexts and intervening conditions, thereby leading to various student outcomes.

Causal Conditions Related to Student Motivation in PS

In order to avoid confusion surrounding the term "causal" as used in this study, it is necessary to note that the phrase "causal conditions" was used throughout this manuscript because that is the language of Strauss and Corbin's (1990) paradigm model. The findings in this study are not presented as causal in the sense of "x leads to y." Instead, causal conditions were consistently associated with and related to the occurrence of the central phenomenon (i.e., student motivation) as determined by the analysis of

Table 2 Open and axial coding categories with corresponding properties and dimensions and examples from the qualitative data

Category	Properties	Dimensions
PS motivates and engages students in science	Intensity	Low–high
	Connection to project	Superficial–vested
Examples		
"They [mentors] have elevated the seriousness of the experiments" (Teacher comment about intensity of student engagement)		
"I'm sad to see this [project] come to an end" (Student comment about connection to the project)		
Student empowerment	Ability to choose	Low–high
	Attention to ideas	Ignored–valued
	Personal endorsement	Low–high
Examples		
"We got to choose the experiment!" (Student comment about ability to choose)		
"They are empowered. Those kids are empowered" (Teacher comment about student empowerment as a result of PS)		
Online mentor interaction	Frequency and timing	Delayed/few–prompt/many
	Tone and demeanor	Controlling–partnering
	Style (subset of tone/demeanor)	Declarative–questioning
Examples		
"If the mentor does not reply, the mood is down" (Teacher comment about importance of timely feedback)		
"Our mentor is not very nice to us" (Student comment reflecting reaction to controlling demeanor of mentor posts)		
Authenticity of experience	Context of study	Books–living plants
	Collaborative opportunities	Low–high
Examples		
"In class they [students] do not get what science is. PS provides opportunities for them" (Teacher comment about authenticity of the PS experience)		
"I wish I would have caught on to your experiment earlier…I'm interested in hearing what your results are…I'll be eagerly waiting for the results of your experiment" (Student comment about collaborating with another group online)		
Curricular module	Ambiguity (# of variables)	Low–high
	Novelty	Low–high
	Freedom for creativity	Scripted–open-ended
Examples		
"The PS site is both novel and complex…I do scaffolding…for my students" (Teacher comment about high degree of novelty for students)		
"Muck around" (Teacher comment about having the freedom and complexity in a module so students can explore and be creative)		
Orchestration	Expectations of actors	Unclear–clear
	Scheduling	Poor–appropriate
	Experience of actors	Novice–experienced
	Communication between actors	Low–high
	Scaffolding	Poor–adequate
Examples		
"Students want something…mentors want something else…as teachers we are in the middle of two different request" (Teacher comment about unclear expectations)		
"For PS to work, scaffolding is critical. If students get frustrated, it is over" (Teacher comment about necessity of adequate scaffolding)		
Student characteristics	Initial motivation level	Low–high
	Inquiry experience	Novice–experienced
Examples		
"I'm sorry to hear you ladies aren't excited about science, but I understand. I know it can be hard and frustrating, but it can also be really fun" (Scientist-mentor comment about students' initial low level of motivation for project)		
"I don't know much about plants, and science is not my favorite subject" (Student comment about lack of experience)		

qualitative data. The debate about the use of qualitative data to make causal claims is well documented (see NRC 2002; Maxwell 2004) but is beyond the scope of this paper. So, in accordance with the tenets of grounded theory as espoused by Strauss and Corbin (1990), the three causal conditions influencing the phenomenon of increased

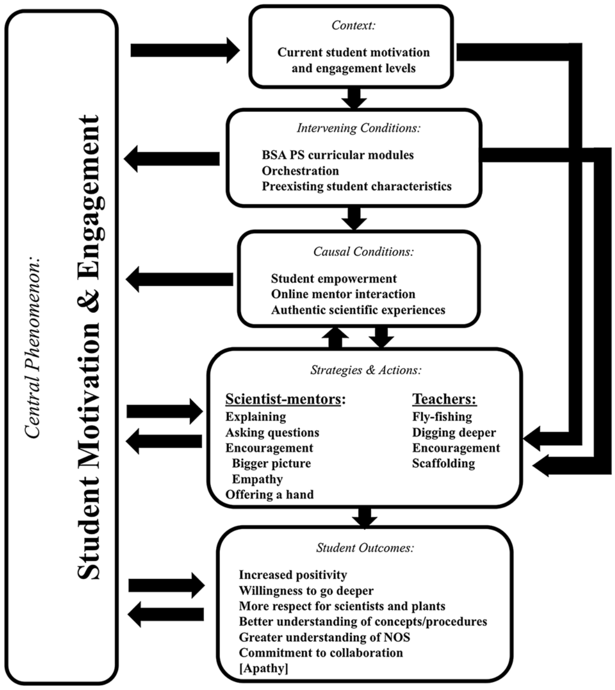

Fig. 1 Overview of categories that emerged from grounded theory analysis arranged in accordance with Strauss and Corbin's paradigm model (1990)

student motivation in this study were: student empowerment, online mentor interaction, and authentic scientific experiences for students (Table 2; Fig. 1).

Student Empowerment

According to focus group participants, students reveled in the ability to choose the contexts for their experiments and took on more responsibility than usual in taking care of their projects. Students owned the experience because they were empowered to ask questions, design experiments to answer those questions, and ultimately evaluate their own projects. One teacher excitedly announced how her students always answered her question, "What do you like most about *PlantingScience*?" with the response, "We got to choose the experiment!" Kelly, the observed teacher from the western USA, echoed those sentiments, sharing how empowering the PS experience was for her students. "They are empowered. Those kids are empowered. I mean, those kids walked in and they had their seeds before the bell even rang. So I feel pretty good about that."

In the online dialogues, student-teams often referred to their experiments in possessive terms, claiming this was "our experiment" and referring to scientist-mentor participation as supplemental to their own. "Thank you for mentoring us on our plant experiment. We are excited to work with you." Interestingly (and contrary to intuition), the relationships between students and scientist-mentors seemed to enhance students' feelings of ownership.

Online Mentor Interaction

The second causal condition was online mentor interaction. PS scientist-mentors assisted students from the start of an inquiry project to its completion. Evidence of the motivational sway scientist-mentors had with students was tangible in many different ways. During observations, it was not uncommon to see students burst into the room before class started, boot up computers, and check for mentor feedback. When scientist-mentors had responded, students celebrated with shouts, "high-fives," etc. Without a response, students' mannerisms and countenance reflected their disappointment. Some voiced their frustrations with statements like, "He didn't respond again!" or "Our mentor doesn't like us!" Students sometimes begged scientist-mentors to respond, posting statements like, "Will you at least give us some positive feedback…or some sign that you're alive?" The *mentor effect* signified the motivation scientist-mentors provided for student-teams through participation in the online dialogues. According to Kelly,

> It [the mentoring component] is huge. Huge. You saw those kids. Man, if their mentor doesn't talk to them, it's, "Our mentor doesn't like us, they haven't communicated with us." The mentor thing is huge, huge, huge. They are so excited when the mentor says something to them. And you know, the level of excitement that is in the room would not be there if it was just me commenting on their experiments. In fact, they would be sabotaging their experiments. The behavior would be completely different. They [mentors] have elevated the seriousness of the experiments.

From the outset of many PS experiments, even "unenthused" students looked to their scientist-mentors for inspiration. "I'm not ready to do this project," wrote one student, "but hopefully you can change my mind." Another echoed, "I am not looking forward to the project, but maybe you will get me excited to do it." These comments and similar ones indicated students *expected* to be motivated by scientists. Whether scientist-mentors were always aware of how their comments affected student motivation was uncertain, but distinct trends in how mentors dialoged with students and how these comments contributed to student motivation were uncovered in this study.

Examination of scientist-mentors' dialogues with student-teams indicated the frequency and timing, tone, style, and demeanor of mentor responses was important to students. Kelly understood the importance of frequent and timely mentor feedback on her students' motivation. "Our emphasis has been on their dialogue with the mentor…I have focused more on making sure they are communicating with their mentor. Unfortunately, some of the mentors are not communicating with them." When mentors' responses were frequent and timely, student motivation increased. For example, a student in Kelly's class logged on to the PS website and exclaimed to other classmates, "Holy cow! He [mentor] gave us a really long reply!" Students from other teams immediately clustered around the laptop, eager to get a view. After reading the response, this team immediately began formulating their response. This scene illustrated the motivational value of scientist-mentors' responses.

In like manner, students were amotivated by lack of responses or delayed responses. Some student-teams implored their scientist-mentors to "reply back to us soon!" Other teams expressed their frustrations with scientist-mentors who did not respond. A student from another school commented on one of Kelly's student-team's page: "Your communication with your mentor is awesome. You're lucky to have one that is interested in your project. Very creative! Congrats to your mentor for being so involved." Sometimes, it was apparent that scientist-mentors recognized how important frequent and timely feedback was to students. Mentors sometimes included comments like, "I'll make sure to check back here tonight, in case you get back right away" or "Sorry about not responding on Friday."

When scientist-mentors were demanding in their comments, students sometimes lost interest in their projects or complained about their mentors. Scientist-mentor comments such as, "Hurry up and come up with any ideas," and "Why did you start with only six seeds? Wouldn't it be better to have at least 10?" did not endear student-teams to their mentors, as evidenced by comments students made during observations. Teachers also noticed the effects of these kinds of comments on students. Kelly recalled,

> One of the kids said, "Our mentor is not very nice to us." And so I read her comments, and she is not very nice. She's just like "Roar, roar, roar!" And I don't want them [scientist-mentors] to be cheerleaders, but at the same time, I think the kids are excited. And when they get nothing but, "Yeah, but" [from their mentors], I think it is hard for them to maintain their joy and wonder.

Authentic Scientific Experiences for Students

The third causal condition was authenticity. PS provided students with opportunities to participate in authentic scientific tasks such as developing research questions, devising analytical methods, performing analyses, and generating conclusions using real specimens (see Chinn and Malhotra 2002). The authenticity associated with PS projects was a contributing factor to increased student motivation and engagement. In fact, the use of living plants in experiments was one of the most prominent contributors to authenticity for students. Some students personified their plants, referring to seed germination as "saving the babies." Additionally, teachers in the focus group revealed how PS provided many students with a first-time, hands-on experience with plants. Students often wrote in the online dialogues about their excitement with the plants. "I am sooo happy because our seed actually sprouted over the weekend…I went out into the hall and said 'I have not failed!'"

Opportunities for collaboration also contributed to the authenticity of the experience for students. Teachers in the focus group prized how PS enabled students to switch from individual activities to more collaborative and group-based scientific inquiry activities in which students communicated and exchanged ideas with other groups and with real scientists. In some cases, students got interested in other groups' work and exchanged ideas in online discussions. Consider the following comment posted on an exemplary student-team's project site by a student from a different school:

> I wish I would have caught on to your experiment earlier. It looks pretty awesome! I'm interesting in hearing what your results are. Just earlier today I was thinking about my own experiment and wondering… Your experiment follows along with my thinking… You guys have done an excellent job! I'll be eagerly waiting for the results of your experiment. And thanks for commenting on my own team's experiment!

Students in PS crossed classroom and school boundaries to not only communicate with scientists, but also share with other students involved in the same types of projects.

The Context Most Affecting Teachers' and Scientist-Mentors' Strategies and Actions

Context refers to the conditions within which participants take action and devise strategies (Strauss and Corbin 1990). One of the main variables affecting teachers' and scientist-mentors' strategies was the motivational level of their students at a given time. Not only did students start PS with different levels of motivation, their motivation also fluctuated over the course of the experiment. The strategies and actions used by teachers and scientist-mentors, whether in person (i.e., teachers) or online (i.e., scientist-mentors), were dependent upon the engagement and motivation levels of their students at a given time.

Strategies and Actions Affecting Student Motivation and Engagement in *PlantingScience*

Teacher Strategies

Figure 1 shows the different strategies and actions teachers used to promote student motivation and engagement in the classroom. In contrast to controlling environments that often alienate students (Urdan and Turner 2005), successful PS teachers incorporated strategies like “letting go.” By letting go, teachers turned the responsibility of learning over to students and allowed them to exert more independence and creativity. Kelly used the following analogy to explain what she meant by letting go.

> I kind of see it like fly-fishing. You let it out a little ways and maybe they are working on one or two parts of an inquiry. Then you pull it back in and debrief it. This [*PlantingScience*] is an example of where I have let my line out all the way, let them do what they need to do, then we will debrief it.

Similarly, Dan, the teacher from the Midwest who was observed, believed in letting students explore.

> You have to let the kids do their thing. You have to let them pour dirt all over your floor, because that is what happens. …It’s not the end of the world. But you also need to teach them that you need to be accountable for that, you need to be more careful about that so it doesn’t happen more often. And then you have to let them come up with their dumb ideas and work them in to higher level thinking ideas. They are just so used to grabbing these low level thoughts and calling that education because that is what they have gotten away with for so long.

PS teachers also pushed students to go beyond the superficial, dig deeper, and wrestle with larger ideas and explanations. For example, Dan challenged students by saying, “You need to explain why you think what is going to happen is going to happen. You need to do science.” In the interview, he elaborated, “I always want their questions to be higher level questions. I always want them to look more deeply than they do.” While reflecting on the process of creating an environment ripe for deeper engagement and less superficiality, Dan shared,

> Most kids walk around with more content in their pocket than we can ever begin to teach…if you can Google it up, you don’t need to memorize it…and we need to allow that in the way that we educate. We need to teach kids to think. And *PlantingScience* is a way of thinking, a way of doing things that allows you, forces you to think, that causes you to be creative and that sort of thing. Those are the things, the benefits that we get…

In like manner, Kelly challenged her students to take their analysis to another level. She provided an immersion time before students started their experiments, effectively driving students to the literature, raising the levels of their research questions, and providing a solid foundation for subsequent research. She shared,

> I think that giving the first two to three weeks over to just letting them fish around has made all the difference in the world. At first they were coming up with real lame, basic questions, and they were not wedded to the questions. I just kept telling them, “Let’s learn more about seeds and talk to your mentors.” And, I gave them some articles to read about gravitropism, phototropism, showed them some examples of experiments done by Darwin where he cut off the root tip and looked at the meristem growth. So then it piqued their interest more, and they’ve created questions they are more committed to.

While both Dan and Kelly expected more from their students, they also provided the necessary support to keep students engaged and not frustrated. In their own unique ways, both teachers used encouragement to keep motivation levels high and attitudes positive. Although intervening conditions will be discussed shortly, it is useful to interject that one intervening condition in particular, pre-existing student characteristics, greatly influenced the specific encouragement strategies used by Dan and Kelly. Dan’s young students, by his own account and from the classroom observations, were not experienced with open-ended inquiry. As a result, Dan’s strategies in the classroom were somewhat different than those employed by Kelly, whose upper level students had more experience.

Dan confidently challenged students to step up to new levels of responsibility and learning.

> I told them [students] very specifically at the outset [of the PS unit], “Now we are going to diverge, and we are going to be doing two things at one time. So we’re essentially doing what the other classes are doing [i.e., the standardized curriculum], but we are also doing this experiment. So that is going to be challenging for you all, but I think you are up to that challenge, and I think you will get it.”

For Dan’s inexperienced learners, this process was often difficult. He constantly reminded them to be independent and quit using him as their primary source of information. Basically, Dan used a “heavy-handed independence” style of encouragement. While he certainly did not dictate to students what to do and how to do it, he was demanding and persistent with his explicit reminders to "do science." In contrast, Kelly used more traditional strategies of encouragement, including positive reinforcement. Her students had enough experience with inquiry to be somewhat comfortable with the ambiguity, and they often just needed a positive comment to keep them going.

While encouragement was important, teachers also successfully motivated students using other types of support. According to focus group teachers, the added complexity of the online component and the mentoring from scientists made scaffolding necessary for successful PS implementation. One teacher commented, "The PS site is both novel and complex. Not only are students doing rigorous science, but they are also communicating with a new person. I do scaffolding so that the environment is not as novel or complex for my students." Another teacher added, "For PS to work, scaffolding is critical. If students get frustrated, it is over." Obviously, teachers employed scaffolding in an effort to keep students engaged and motivated while participating in all of the nuances of PS.

Kelly provided students with early supports for using the PS platform by incorporating innovative activities such as an online scavenger hunt.

> I had students conduct a scavenger hunt that was very successful. I had them look at the STAR [exemplary] projects and identify the dependent and independent variables, for example. Tell your students to familiarize themselves with other projects. Tell them to go see other projects.

From all accounts, students became more independent in their learning over time through scaffolding efforts. This trend was reiterated by focus group teachers who shared how familiarity with the PS program reduced the complexity and increased the engagement of students over time. "When they do two grade-level projects in a row, there is an increase in their ability to do the experiments and use the platform," one teacher commented.

Mentor Strategies

In addition to teacher strategies, various scientist-mentor strategies contributed to student motivation (Fig. 1). For example, scientist-mentors often explained scientific processes and procedures to students and/or shared relevant examples and analogies. One mentor explained to his student-team:

> By four pots I mean 2 that have soil with barley seeds planted in them and 2 that [have] sand with barley seeds. This is what we call replicates. We replicate each treatment so we can determine whether or not our results are applicable in general. If we only had one pot of each treatment and something really weird happened like all the plants died or they never germinate, we wouldn't have another one just like it to look at and figure out if what happened is normal [or] if there was something weird going on with those particular seeds or soil. Replicates make your results more reliable.

Many scientist-mentors chose to engage students with questions instead of directives. Questions can be less threatening than direct comments, particularly when other social indicators such as body language and voice inflection are missing (e.g., in asynchronous online textual dialogues). Questions such as, "What kind of data will you collect to determine which grows better?" and "What else do you think about this experimental design?," required students to think carefully about their experiments and results.

In one dialogue, a scientist-mentor, perhaps sensing students lacked relevant background knowledge, asked a probing question to persuade students to think carefully about their interpretations of an outcome from their experiment. "Sugar is a good source of energy, but what do boron and calcium provide to the pollen tube? How do they help the pollen tube to grow, or do they?" In this example, the scientist-mentor used a questioning strategy to provide some additional information, but simultaneously challenged students to seek more information on their own.

Encouragement was also a common theme in scientist-mentors' responses. Mentors made comments such as, "I can't wait to see what happens," and "I look forward to seeing what you find out." General encouragement was common, but scientist-mentors sometimes used more explicit strategies of encouragement, usually in response to students' apathetic comments. For example, when students posted disparaging comments, many scientist-mentors responded by providing connections between the science in the PS project and scientific endeavors occurring in the real world. In one case, students from the same team conveyed, "Personally I'm not a fan of science" and "I personally don't like science. Science is kind of hard for me." In response, their scientist-mentor offered a greater vision of scientific discovery and also outlined the historical and contemporary contributions of plants to the world.

> Just imagine all the questions you can ask and answer with science! And plants, oh the plants, they are so amazing! We wouldn't be here without them! Early in our world's history, small plants in the ocean converted carbon dioxide to oxygen, drastically changing the atmosphere and allowing animals to live and breathe. They are still today essential in converting carbon dioxide to oxygen, and without them we would all suffocate!…Besides just breathing, we

> depend on them for food and purifying our water….Take a minute and think about how many different plants you eat everyday. Of course there are fruits, vegetables, but anything you eat with wheat, or corn is also made from plants! Even the meat you eat (if you eat meat) depends on plants!…So, plants in a word, are awesome. Do you believe me yet? I can go on and on if you are interested;).

Instead of berating the students for their short-sightedness and apathy, this scientist-mentor tried to connect them to a bigger picture and help them see the relevance of plants and plant science.

In other cases, scientist-mentors expanded students' perspectives by making connections between what the students were doing in the classroom and what scientist do in the field. For example, one scientist-mentor explained to his student-team, "I am a plant ecologist with a big interest in the effects of herbivores on plants, and your approach is very interesting to me because there are often times that herbivores can promote seed germination by munching through the seed coat." Through this simple communication, the scientist expressed how the student-team's approach was similar to what she was doing as a professional scientist, thereby connecting students' perspectives with a bigger picture.

In addition to painting a bigger picture, scientist-mentors also expressed empathy for students who disliked science. In response to students' derogatory remarks about science, a mentor posted, "I'm sorry to hear you ladies aren't excited about science, but I understand. I know it can be hard and frustrating, but it can also be really fun." In another case, a student-team expressed annoyance regarding the unexpected demise of their fledgling plants. Instead of pointing out what they could have done better to keep the plants alive, the scientist-mentor responded with a gentle, "I am disappointed too, for you, but I am glad that you are carrying on!" Other scientist-mentors acknowledged difficulties with statements such as, "Science is always a challenge (even a small experiment)." In most cases, scientist-mentors combated student-team frustrations with empathy and understanding as opposed to disgust and/or condemnation.

Scientist-mentors in this study were also typically intentional and explicit in their efforts to build partnerships with their student-teams through the online portal. "I hope we will enjoy this together," wrote one scientist-mentor from Dan's class. When student-teams invariably came up against challenges, scientist-mentors emphasized how they were partners in the process and would help the team get through the difficulty. "Together we can determine whether the problem of drying out of plants is a general problem or not, and just how to proceed to deal with it," explained one scientist-mentor. All of these statements served as positive reflections of the relationships forged over several weeks of scientific partnership.

Student Outcomes as a Result of Teacher and Scientist-Mentor Strategies

Teachers and scientist-mentors used diverse strategies and actions while doing PS, and students responded in various ways. In accordance with Strauss and Corbin's (1990) paradigm model (Fig. 1), the student-teams' responses to the actions and strategies of teachers and scientists were deemed outcomes. The student outcomes as a result of PS participation formed a critical part of the grounded theory generated in this study.

Sometimes, the actions and strategies of teachers and scientist-mentors made a difference in students' motivation. For example, 3 weeks after their scientist-mentor made an empathetic post and tried to connect the students' work to a bigger picture, one student-team shared how they changed their experiment. "We changed our research question and our research prediction. We decided to change it because of your [mentor's] comments. We thought that we should change it after talking to you and our teacher." In other words, the efforts of their scientist-mentor and their teacher (Dan) ultimately had an impact on how these students approached their project. The input of the scientist-mentor and teacher prompted students to put in extra effort to improve their project. This is only one general example of how the strategies and actions of teachers and scientist-mentors made a difference in student outcomes. Several additional student outcomes were uncovered including: (1) increased positivity, (2) willingness to take projects deeper, (3) more respect for scientists and plants, (4) better understanding of scientific concepts and procedures, (5) greater understanding of the nature of science (NOS), (6) commitment to collaboration and, unfortunately, (7) apathy toward science.

Increased Positivity

Students often posted positively in response to mentor feedback. Many thanked their scientist-mentors with simple expressions like, "It was good to hear back from you. Thank you for giving us good advice." Others expressed positive thoughts about the feedback itself. "I think that sounds like a good idea. I like it." Some student-teams used more affective expression than others when thanking scientists. "Thanks for complimenting our photos and giving us some suggestions…We greatly appreciate it! And we will also take you up on those suggestions to better our data. Thanks again [scientist-mentor's name], you are so inspiring…;)."

In the midst of many examples of increased positivity, the story of one student in Kelly's class stood out. Baird (pseudonym) introduced himself on the online portal as a 16-year-old junior. He admitted to his mentor that, "I don't know much about plants, and science is not my favorite subject." As the PS experience began, Baird and his team seemed to take ownership of their project, often assertively informing their scientist-mentor about results and new directions they wanted to take the project. Baird's team developed a great relationship with their scientist-mentor, Mona (pseudonym). From the beginning, Mona showed interest in the project and in the students themselves. She posted statement like, "I enjoyed reading your introductions" and "I see you won your first football game last week." In response to some of Baird's and his teammates' negativism toward science, Mona wrote,

> I know that some of you are interested in fields that you feel may have nothing to do with science. But, being able to collect and analyze data is an important skill you can learn from projects like this and apply to many other fields.

Along their journey together, Mona valued the student-team's questions and showed interest in partnering with them for the duration of the PS experiment. When Baird's team posted its research question, Mona responded, "Your question is very similar to the same kinds of questions environmental science consulting firms address when they look at levels of contaminants in water or soil." Mona was not controlling in her comments, often insinuating ownership of the project belonged to the students. "I look forward to hearing about your ideas for designing your experiment." While explicitly understanding of their ownership, Mona was quick to offer her partnership. "We can then work together to flesh out your experimental design."

Throughout the process, Baird and his team reached out to Mona, often asking for help. "We have decided to do intervals of 5 starting at no fertilizer and going to 25. Do you think that is an appropriate interval? Does it go high enough?" On another day, Baird posted, "My concern is that we have not imbibed our seeds until today, and we are not going to have enough time this week to observe much." Mona provided suggestions and encouragement such as, "You are making great progress, and I will be checking back soon." In addition, Mona mentioned students by name when appropriate, writing things such as, "In regards to Baird: I would suggest recording how many seeds successfully germinated and then just determining growth rates for the individual plants. I look forward to seeing more of your results this coming week."

In spite of some apathy early on, Baird's comments became more positive. He proudly proclaimed on the online portal, "Our plants are growing really fast!" Baird also commented on other students' projects, indicating interest extending past his own student-team's project. Baird posted the following on the page of another group: "Great job!!!! I think that this was a cool experiment. It's interesting to find out that green tea helped the growth." The most telling bit of evidence indicating an increase in Baird's motivation for the project was his last post. "We will be uploading our final project soon. It has been an interesting experiment. I'm sad to see this come to an end."

Willingness to go Deeper

It was evident many student-teams went above and beyond basic engagement during their PS projects. Students often completed outside research to help them form conclusions, an indication of their willingness to go deeper. Others were willing to use new equipment to answer their research questions. One student-team had a long conversation with Kelly about how to measure the rhizoids of their tiny plants without damaging them. Ultimately, with direction from Kelly, they decided to use a special software program to analyze pictures of the plants and determine lengths of the rhizoids in an unobtrusive fashion. They gleefully reported to their scientist-mentor, "We are planning on taking pictures of the seeds, then with a certain software we have we will be able to measure the length of the rhizoids." The eagerness of these students to learn a new software program signified their willingness to go deeper. The excitement with which they shared these ideas with their scientist-mentor was also indicative of the motivation and buy-in they had for their PS project.

A final piece of evidence indicative of deeper engagement on the part of students was how willing students were to question their procedures and collaborate within their student-teams and with their scientist-mentors on ways to improve the process. Students were extremely conscious of their work, often going to painstaking lengths to insure consistency and accuracy in both the care of the plants and in data collection. For example, after imbibing seeds for almost half of a class period, one student in Kelly's class spontaneously threw up his hands and shouted, "We should have measured them before putting them in water!" After a quick collaboration, the team agreed to start over with new seeds, this time making sure to mass the seeds before starting imbibition. Similarly, other students were willing to go the extra mile during the PS project, often coming to the classroom outside of their normal class hours to check results and take care of their plants.

More Respect for Scientists and Plants

Good communication between scientist-mentors and student-teams helped students realize scientists were "real people with real jobs." Teachers in the focus group reported students saw scientists as "cool" after a PS project. Also, several teachers remarked how PS changed learners' attitudes about plants. Instead of "boring," students came to view plants as "neat" and interesting.

Better Understanding of Scientific Concepts and Procedures

In most cases, student-teams were eager for scientist-mentors' help, often asking content and procedural questions. "Should we limit ourselves to two different seeds, or should we try to experiment with more than that? How many would you recommend?" "Do you have any suggestions for us this far?" In many instances, students acknowledged that scientists' explanations helped them understand concepts and scientific procedures better. Common student feedback included comments like, "I learned a lot from your comments and will be sure to take the advice and the things I have learned into account in future experiments" and, "Your knowledge is a gift, and it was so helpful."

Better Understanding of the Nature of Science (NOS)

Feedback emphasizing the NOS was commonly provided by scientist-mentors in the online dialogues. Learning about NOS issues was new for many students. One teacher expressed, "In class they [students] do not get what science is. PS provides opportunities for them." PS gave students real variables within the context of scientific inquiry and allowed them to have conversations with scientists about their authentic projects. Dan heralded the way PS provided relevant experiences to supplement book knowledge, and he was excited that students could learn about the nature of science in an authentic context:

> I like the fact we were able to take this experiment that we are doing and relate it back to what we studied. To remember that the scientific method that we studied first talks about observing, questioning, creating a hypothesis, then doing the experiment. So here are these steps that we just did in real life, based on what we were talking about. And this is one way we do science. Trying to directly connect what we are doing with the fact that science is a way of knowing, science is a collaborative effort. We are collaborating with scientists, we are showing our work to the world.

Commitment to Collaboration

Dan offered an insightful reflection on the value of teaching students about collaboration. "Science is not done in a vacuum, and it's certainly not done in secret," he mused after a day of PS activities. "Talk to the class about it [your PS project]. Talk to the world about it!" he constantly encouraged his students.

Likewise, many of Kelly's students had collaborative dispositions, often showing genuine interest in other student-teams' projects. One particularly novel project in her class was an investigation of the effects of motion on seed germination rates and subsequent seedling growth. Students in other sections who saw the project began to actively communicate with this group via the asynchronous portal. One student posted, "I'm excited to find out why that is doing that [i.e., discover why beans are losing mass]." Teachers in the focus group agreed that students needed to participate productively in science through collaboration, and, by all indications, students enjoyed doing so through their participation in PS.

Apathy

Although PS was and is an overtly successful program that has been called many superlatives such as "magical," it is not a cure-all for student apathy. On occasion, in spite of the best strategies and efforts of PS curriculum developers, teachers, and scientist-mentors, students responded apathetically to the program.

For some of the learners in Dan's classroom, the novelty of the project and the fact that it required a lot of independent action was too much to handle. Some of these students apathetically crawled along, constantly needing Dan's prodding verbiage to get anything accomplished. These students included one girl who constantly complained and sat in her chair with her hoodie pulled over her head. Another was a boy who sat at the back of the room, directly in front of the observation video camera. He had to be awakened multiple times by his tablemates who enthusiastically kicked the table leg to disrupt his restful slumber.

One student-team in Dan's class never really engaged in their project. They introduced themselves to their scientist-mentor and began as many other teams. Their scientist-mentor was responsive, consistently posting appropriately and trying to generate some enthusiasm. Dan even posted in the online forum, which was a very uncommon practice for teachers. He wrote, "You are currently way behind…you need to show the world what's up." Instead, this student-team never posted again, leaving their scientist-mentor to write, "I haven't heard from you in a while, and I'm interested in knowing how your work is going."

It is interesting to note that halfway through the project, this student-team posted, "Our Canadian thistle hasn't sprouted yet, there is something wrong." The next day, they followed with, "The Canadian thistle still hasn't sprouted, even though the book said it would in 2 days. We even put more in a Petri dish and they didn't sprout either. We did some research and found out that they had been heat treated." While it is beyond the scope of this study to ascertain what happened to this team, it stands to reason they may have lost their motivation due to their plant's failed germination. As discussed previously, working with live plants motivated students, and the inability to successfully germinate a living plant may have been equally demotivating.

Intervening Conditions Influencing Teacher and Scientist-Mentor Engagement Strategies

Strauss and Corbin (1990) defined intervening conditions as "structural conditions bearing on action/interactional strategies that pertain to a phenomenon" (p. 96). Three intervening conditions emerged in this study that affected the strategies used by teachers and scientist-mentors to motivate students. These intervening conditions included the curricular module, orchestration of the learning environment, and preexisting student characteristics.

Curricular Modules

PS curricular modules included the content and formed the basic structure of the botanical investigations. According to focus group teachers, well-constructed modules provided scaffolding for learners, direction for the teacher, and opportunities for the involvement of scientist-mentors. Successful modules, according to the focus group, allowed for maximum student creativity through open-ended inquiry. A successful module combined novelty, discrepant events, and multiple variables in such a way that students could "muck around" to learn how the variables affected each other.

Both Kelly's and Dan's students were involved in *The Wonder of Seeds* germination module. Focus group participants noted how this module, in particular, met all of the necessary criteria for good inquiry. As a result, the module was a positive intervening condition in both sets of classroom observations performed in this study. Under differing circumstances, however, a module allowing less freedom or opportunities for students and scientists to communicate might contribute negatively or neutrally to student motivation.

Orchestration

While orchestration traditionally refers to the role of the classroom teacher in managing the science-learning environment (e.g., see Duschl et al. 2007; Michaels et al. 2008), the complexity of a blended environment such as PS required orchestration be shared among all participants. Focus group participants agreed that orchestration of the complex learning environment was an important condition related to the success of PS. One of the most obvious ways Dan and Kelly orchestrated the PS project was by providing time on the computers for students to communicate with scientist-mentors. Both teachers were explicit in their instructions to keep scientist-mentors in the loop. Both classrooms had access to the Internet through laptops brought into the classroom on mobile carts or by hand. Keeping open lines of communication with scientists was an obvious priority for both teachers.

Focus group teachers echoed the importance of orchestrating time and opportunity for students to communicate with scientists. One teacher said her role was "to encourage kids to interact with their mentors." Another teacher stated, "I try to basically reinforce the idea that the mentor is the expert." Another explained how she often gave students explicit directions like, "complete their posters and speak to the mentor and post in their journal." When all parties recognized the "need for deeper communication all around" and took steps to keep communication open and consistent, students seemed more engaged in the PS projects.

Successful orchestration was also dependent on experience. In general, PS seemed far less complex as participants became more familiar with the program. For teachers who chose to persevere, orchestration became simpler as they discovered and developed new strategies to reduce the overall complexity of the innovative PS learning environment. One teacher admitted, "It was difficult for my first classes, but I have persisted, and it has gotten better." The same can be said of the relationship between scientist-mentors and PS. Although mentors never physically entered the classroom, complexity decreased for them over time. Orchestration became simpler when they developed their own strategies to effectively communicate with and support students through the online portal.

Student Characteristics

Two preexisting qualities of students were classified as intervening conditions because they affected how teachers and scientist-mentors interacted with students and how students engaged in the PS project. The first was student experience with inquiry in general and perhaps PS in particular. When focus group teachers discussed this factor, they agreed that more experience typically associated with greater engagement and motivation. One veteran teacher shared, “When they do two grade-level projects in a row, there is an increase in their ability to do the experiments and use the platform.” These teachers also discussed how students built on previous year’s studies to create even better projects. “Students who talk to each other from year to year or repeat PS during the same school year increase project quality.” However, teachers were quick to point out that just because students were new to the project did not mean they could not produce quality projects and be excited about PS. “There is a steep learning curve, but you know when they get it,” offered one teacher.

The second preexisting student characteristic affecting strategies and engagement was students’ motivation level at the beginning of the project. When students were apathetic in the beginning, as evidenced by comments such as, “Botany isn’t my favorite subject in school,” and “Science is not my strongest class,” teachers and scientist-mentors used different strategies than when the students came into the project motivated and excited. For example, scientist-mentors facing apathetic students used strategies of encouragement such as looking at the bigger picture and empathy (Fig. 1). Contrarily, when dealing with students who “love plants and am very excited to do this project!” scientist-mentors were more likely to ask questions and offer their partnership.

Implications

PS is a complex learning environment composed of sophisticated cogs that intricately fit together to form a system that, in the best cases, led to student motivation and engagement. However, simply knowing that PS motivated students was not enough. Researchers were more interested in identifying specific factors that prompted students who were sick at home to log into personal computers and report to their teammates and mentors that, “This is the first day I have been out of bed since Monday night. I am excited to read about the progress of our plants” or “I am sick and could not make it to school but I will be on the computer at the same time you will be so you can tell me what you are doing with the plant and stuff.”

While several factors were identified that contributed to the popularity of PS from participants’ points of view, they were not independent components. To the contrary, the causal conditions were influenced by the strategies and actions of teachers and scientist-mentors. The strategies and actions of teachers and scientist-mentors depended upon intervening conditions that were affected by context. Moreover, all components had properties and dimensions that changed in real-time and consequently affected all other variables in slightly different ways (Fig. 1; Table 2). Nevertheless, the grounded theory outlined in this study provided a more robust understanding of why PS has experienced growing popularity in K-12 classrooms. The findings in this study contribute to ongoing conversations about science education, online/blended learning, and student motivation. Furthermore, they provide insight into the roles of teachers, scientists, and curriculum developers in blended learning contexts.

Teachers

Teachers obviously play a pivotal role in the success of programs like PS. Even when supplementing their own instruction with online discussions, research findings indicate teachers must place value on involvement in the online activity or students will neither value the experience nor persist in their participation (Xie et al. 2006). Hartnett et al. (2011) concluded that, “Practitioners need to be cognizant of the important role they play in influencing learner motivation…” (p. 33). Many teachers appear to be embracing this role, as evidenced by studies indicating teachers saw their most important job as motivating students and helping them become responsible for their own learning (Bryan et al. 2011).

The findings in the current study emphasized the importance of teachers empowering students with choice in the classroom. PS provided a unique opportunity for students to develop their own research questions and strategies, but only because teachers allowed that to happen. Past research has shown that students exhibit more enthusiasm toward learning science when they were empowered by teachers to pursue their own interests in the science classroom (Sanfeliz and Stalzer 2003). Dan, Kelly, and the other teachers in the focus group allowed students the freedom to explore and “muck around,” and their students benefitted tremendously from that freedom and autonomy.

One point that cannot be lost in the discussion is how Dan and Kelly managed the pressures of standardized testing along with PS implementation. Standardized testing pressure has led some teachers to seize greater control in the classroom and alienate their students (Urdan and Turner 2005). Both Dan and Kelly balanced the open-endedness of PS with the rote activities of standardized testing preparation. While this increased the orchestration difficulties for both teachers, they expressed it was worth the extra effort. Nevertheless, teachers who wish to implement innovative curriculum like PS should be aware of the challenges of orchestrating a complex learning environment blending the use of computers, hands-on laboratory, and mentor interaction while still trying to offer the standard curriculum which sometimes does not include these components.

In spite of all the challenges, this study bears witness that teachers can successfully orchestrate the complexities of PS in ways fostering student motivation. The teachers in this study empowered their students through open-ended activities where students pursued answers to their own questions. The teachers challenged students to dig deeper, encouraged them with positive reinforcement, and provided appropriate scaffolding. While using programs like PS can be extremely challenging, the evidence presented in this study implies PS works in part because of the contributions of dedicated teachers who are willing to let students work in complex learning environments.

Scientists

While teachers directed and orchestrated the classroom environment, scientists focused on mentoring and giving their student-teams individualized attention. As students navigated the novelty and complexity of their new-found learning environment, scientist-mentors stepped in and became partners who offered their expertise to students. The mentor effect was a powerful driver as students looked forward to working with mentors, enjoyed having mentors as sources of information, valued mentor feedback, and felt empowered through the partnerships that were forged over the course of their PS projects.

Although students most often turn to teachers for help and mentoring in traditional school contexts (Zimmerman and Schunk 2008), research indicates students will also pursue help and enrichment opportunities from other sources (Newman 2008). Evidence from this study and Scogin and Stuessy (2015) suggests that scientist-mentors contribute to the motivational resources of K-12 learners. These findings are consistent with previous work reporting that students who seek help from adults outside of school sometimes gain motivation for classwork (Guay et al. 2008). Science educators can leverage these findings by forming mentorships between scientists and classroom learners in an effort to increase the authenticity of classroom science and engage students on a deeper level.

When thinking about the formation of successful partnerships between scientists and students in the PS program, two specific factors come to mind: length of contact time and the format of the interaction. First, students typically engaged in PS inquiry projects for three to 10 weeks. In contrast to the findings of Pekar and Dolan (2012) that many scientist-student partnerships are short-lived, PS provided a format that brought scientists and students together for relatively long periods of time. Perhaps the increased contact time contributed to stronger partnerships, a finding consistent with research by Ensher et al. (2003). Second, students may have preferred online communication with scientists because it removed the awkwardness of face-to-face meetings (Rhodes et al. 2006). For many students, seeking help from others can be a daunting task (Zimmerman and Schunk 2008), and the "safer" online environment lowers the anxiety threshold and eases tensions, thereby promoting greater interaction. Both of these factors should be explored in future PS research.

In addition to directly benefiting classroom learners, the PS program and mentoring format has huge implications for scientists as they seek broader impacts on society. In 2007, the National Science Foundation (NSF) explicitly called for funding proposals stressing intellectual merit and broader impacts. Specifically, the NSF mentioned promoting teaching, training, and learning; increasing participation of under-represented groups; enhancing infrastructure for research and education; broadening dissemination to enhance understanding; and benefitting society as ways to have broader impacts (March 2007). Many scientists have struggled with ways to incorporate broader impacts into their research (Lok 2010), and PS provides a unique way for scientists to have direct impacts on the K-12 teaching and learning process. By rendering geographical barriers inconsequential, online mentoring programs provide opportunities for scientists and students to work together like never before (Ensher et al. 2003). In other applications such as at-risk youth counseling programs, online mentoring partnerships have already been realized as tangible ways to unite mentors with protégés on a regular basis (Rhodes et al. 2006).

As evidenced by the findings in this study, scientist-mentors used several strategies to promote positive student outcomes (Fig. 1). While some strategies such as encouragement overlapped with what classroom teachers did, the role of the scientist-mentor appeared somewhat distinct from that of the classroom teachers. Past research has shown that when working with classroom learners, scientists occupy different roles from classroom teachers (Pekar and Dolan 2012). More specifically, Pekar and Dolan (2012) discovered scientists provided conceptual and epistemological support to students while teachers made sure students were able to assimilate the new knowledge.

In this study, the scientist-mentors often emphasized the nature of science and scientific discovery when communicating with students. By using questions instead of directives in many cases, mentors developed an environment of inquisitiveness but still held students accountable for their experimental decisions and conclusions. The implications of this are significant, as national initiatives have emphasized the importance of classroom learners being able to reflect critically on scientific information and participate productively in scientific endeavors (Duschl et al. 2007). PS appeared to be addressing this void, in addition to providing a real-world context for learning. For classroom learners, receiving mentoring from an expert who "has been there and done that" raised the level of authenticity.

While online mentoring provided greater opportunities for uniting scientists with K-12 learners, it was not without its challenges. Of particular interest was how the scientist-mentors in this study navigated the unique asynchronous dialogues with their student-teams. The particular ways they spoke with students may provide insight for all mentors interacting with students through text-based media. The challenges of communicating in asynchronous environments have been well documented (Ensher et al. 2003; Lin et al. 2009), so future research targeting the development of training programs specifically for scientist-mentors who use asynchronous venues seems relevant.

Curriculum Developers

From most indicators, PS was engaging students and creating excitement for plant science and discovery. Since student empowerment was identified as a causal condition, curriculum developers might consider the contributions of purposeful choice toward the motivation of learners when they design science curriculum and activities. In addition, curriculum developers should note that authenticity was an additional causal condition identified through the grounded theory analysis. The use of living plants was a huge factor in motivating students, and the power of being able to pursue questions without known answers was invigorating for most students in this study.

In addition to more autonomous projects with authentic contexts, curriculum developers should also consider how to leverage technology to bring parties together in creative ways (i.e., scientists and classroom learners). Other research on partnerships between scientists and schools has suggested technology should play an important role in increasing the national reach of scientists in future partnerships (Falloon 2013). Although physically bringing scientists into classrooms for face-to-face interactions is challenging, Internet connectivity breaks the logistical and geographical barriers and can foster new relationships between students and scientists in classrooms across the world. These online relationships, which this study showed could be of paramount importance, bring classroom learners "into a world in which they can safely share and engage in discussion and reflection" (Bachman and Stewart 2011, p. 185).

PS has shown promise as a model for bringing scientists and classroom learners together in productive partnerships centered on scientific inquiry. This model suggests that online learning is not just about content delivery, but also provides a means for collaboration and creativity that motivates students in science (as suggested by Bachman and Stewart 2011). By developing more robust curriculum that includes a mentoring component, the field of science education stands to make great strides in providing greater learning experiences for students in motivationally supportive contexts.

Limitations

The sample in this study represented a small proportion of the overall population of participants who used PS through the years. Therefore, a limitation of the study was the ability to extrapolate findings to the entire population. While researchers involved in the PS evaluation project spent time in other classrooms across the country and with other focus groups composed of additional scientists and teachers involved in PS, the sheer volume of qualitative data precipitated bounding the sample to its current size. As mentioned previously in the section on "Analytical Rigor," researchers made extensive efforts to provide robust and reliable findings.

Conclusion

The overall results of this study were encouraging. The findings provided new understandings about a program (i.e., PS) that was positively influencing student motivation and engagement in science education. In addition, this study uncovered specific factors contributing to student motivation, specifically revealing how teachers, scientists, and curriculum developers played a role in the process. The impact scientists had on science learners' motivation through technology-enhanced partnerships was exciting. In the future, perhaps the partnerships facilitated by PS can help solve problems of declining student interest in STEM fields (Toplis 2011) and scientists' struggles to find tangible ways to make broader impacts on society (Lok 2010).

While this study does not make the claim that online mentoring programs involving scientists are the key to turning around science education, the concrete factors contributing to the popularity of PS uncovered in this study are germane to ongoing discussions about increasing student motivation in science education. Intense, field-based investigations of successful programs like PS provide relevant information on how to develop curriculum, use technology, and train practitioners and mentors to utilize strategies and actions that improve learners' motivation to engage in authentic science in the classroom.

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