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Encouraging Greater Student Inquiry Engagement in Science Through Motivational Support by Online Scientist-Mentors

Abstract

Next Generation Science Standards (NGSS) call for integrating knowledge and practice in learning experiences in K-12 science education. *PlantingScience* (PS), an ideal curriculum for use as an NGSS model, is a computer-mediated collaborative learning environment intertwining scientific inquiry, classroom instruction, and online mentoring from scientists. With implementation in hundreds of classrooms across the United States, science teachers have noted PS as successful in motivating their students to engage in classroom inquiry investigations. To investigate the role of the online scientist-mentors in motivating students in the PS learning environment, we used self-determination theory (SDT) to guide a multiple case study of 10 student inquiry teams engaged in PS in a rural public school in a large Southwestern U.S. state. We used online dialogues between scientist-mentors and their assigned student inquiry teams to answer research questions about the motivational support provided by scientist-mentors and the association between this support and students' engagement in scientific inquiry. Analyses revealed a general relationship between scientist-mentor motivational support and student inquiry engagement. Differences were observed in the specific ways in which scientists supported autonomy, competence, and relatedness. Student inquiry engagement corresponded to high support in relatedness, while correspondence with autonomy support was low.

Introduction

The impact of motivationally supportive online mentoring on science education remains largely unexplored. In 2003, Ensher, Heun, and Blanchard lamented there were “virtually no published academic studies to date examining the feasibility or effectiveness of cyberspace” (p. 274), even with the growth of online mentoring. In 2006, Xie, Debacker, and Ferguson reiterated the void, claiming a lack of research addressing students’ motivation to participate in online discussions. In 2010, Chen and Jang published a study specifically addressing the lack of research pertaining to motivational support in online contexts. In 2011, S.W.-Y. Lee et al. published a literature review of studies relating inquiry and technology, citing only one study (see Wang & Reeves, 2006) linking instructional design in Internet-based science learning environments to students’ motivation. With the publication of a special issue of *Education Technology Research & Development* (see Volume 59, Issue 2) and a few other studies beginning in 2011 (e.g., see Moos & Honkomp, 2011; Rienties et al., 2012), we do begin to see that the topic of motivation is receiving a bit more attention in the research literature on online learning. While still not a current “hot topic” for research in educational technology, we concur with Mayer (2011) that concerns about motivation in online learning environments must be addressed.

In this investigation, we accessed a successful “testbed” (i.e., *PlantingScience*) to determine associations between motivation, online mentoring, and student inquiry engagement. Using self-determination theory (SDT) as a framework (Deci & Ryan, 1985), the purpose of this study was to investigate online scientist-mentors’ motivational support of junior high students and evaluate the potential impact of this support on students' inquiry engagement.

Literature Review

The importance of science literacy and critical thinking is recognized globally by many policy makers living in the 21st century, particularly those in modern societies with economies reliant on a well-prepared citizenry and workforce to deal with the consequences of rapid advances in technology (Bryan, Glynn, & Kittleson, 2011). Organizations including the American Association of Colleges and Universities (AACU), the National Center for Educational Statistics (NCES), and the National Research Council (NRC) have emphasized the need for increased scientific literacy and proficiencies in U.S. citizens (Sinatra & Taasobshirazi, 2011). "Science for all" and workforce development share center stage in the latest call for science education reform. The *Next Generation Science Standards* (NGSS; Achieve, 2013) in fact, were developed in response to the poor showings of U.S. students in international studies examining student achievement in STEM related subjects (NRC, 2013) and student interests in STEM career fields (Welch & Huffman, 2011).

The NGSS (Achieve, 2013) proposed an integrated science and engineering framework for raising scientific literacy and encouraging students to seek STEM related careers. The proposal also made calls for promoting active learning, developing authentic scientific communities of practice, and providing motivational support for science learners. Particularly, the NGSS called for students to work collaboratively and actively engage in authentic science investigations using empirical inquiry. In authentic science investigations, students ask their own scientific questions, derive their own hypotheses, develop methods for testing their hypotheses, and construct logical conclusions as evidence-based arguments to defend their conclusions. This type of science learning allows learners to think and act like scientists; it is active, engaging, and provides opportunities for “communicating and critiquing ideas in a scientific community”

(NRC, 2012, p. 127).

Providing an authentic scientific learning community is not easy, however. Chinn and Malhotra (2002) provided a comprehensive framework for evaluating authenticity in science classrooms. These researchers compared truly authentic science, such as that carried out by scientists in their laboratories, to classroom science. Due to the fact that space, time, finances, and expertise often limited classroom science, Chinn and Malhotra reasoned that science educators incorporated less complex tasks than those carried out by scientists. However, these researchers noted that science teachers can still emphasize authenticity by mimicking the cognitive tasks of real science, such as generating research questions, designing studies, explaining results, developing theories, and studying the research of others. Additionally, Chinn and Malhotra emphasized epistemological aspects of authentic science, including evidence-based reasoning, use of theory, discounting of anomalous data, heuristic reasoning, and social construction of knowledge through expert review and collaboration. Authenticity could be met, they concluded, in classrooms affording students opportunities to engage in tasks requiring authentic reasoning, providing frameworks to help students understand the strategies of scientists, and developing methods to teach students authentic reasoning.

In an effort to address the challenges of promoting authenticity in science education, the NRC (2012) placed special emphasis on transforming classrooms into contexts for scientific communities to reflect science as "a body of established knowledge and a social process through which individual scientists and communities of scientists continually create, revise, and elaborate scientific theories and ideas" (p. 73). Mentoring, especially when conducted by professionals, is one practical way to build communities and increase authenticity by raising the level of expertise and the opportunities for collaboration (Mullen, 2011).

Scientists as Mentors

Programs uniting students with scientists in research apprenticeships have become increasingly popular. Sadler, Burgin, McKinney, and Ponjuan (2010) identified 53 publications about apprenticeship programs designed for secondary students, undergraduate students, and teachers. Within programs designed for secondary students, those involving student-scientist partnerships (SSP) usually limited students to collecting data for use in preexisting scientific research projects. Technology was often used to facilitate collaboration between the students and scientists, but the involvement of the scientists ranged from “very limited (e.g., advisory role in the design of the project) to quite extensive (e.g., working with students as they learn data collection techniques)” (p. 240). While SSP models represent one way to implement scientist-student partnerships in the classroom, they sometimes lack comprehensive authenticity because participation is limited to one part of the scientific process (e.g., data collection). In contrast, Chinn and Malhotra (2002) called for a much broader scientific context in classroom environments to emphasize authenticity, both cognitively and epistemologically.

Researchers often report positive outcomes when scientists and students partner together. For example, Bryan et al. (2011) reported high school students' perceptions of science as more relevant and science careers as more interesting when scientists from the community shared their experiences and challenges. Edelson (1998) also reported increased scientific authenticity in the classroom and significant learning gains in programs partnering high school students with atmospheric scientists in inquiry-based activities.

While connecting scientists with students can increase positive student outcomes in science, barriers of isolation often exist to prevent this practice from becoming widespread policy. A recent report from the National Science Foundation (NSF; 2013) drew attention to the

general lack of access of scientists for face-to-face mentoring of students learning science. While the report highlighted the economic ramifications of isolation, the NSF also discussed the logistical and geographical barriers limiting scientists' opportunities to work directly with students in face-to-face classroom learning environments. Capabilities do exist, however, for the use of the Internet to facilitate interactions and foster new relationships between students and scientists in classrooms across the world.

Online Mentoring

Online mentoring benefits students in many ways (Ensher et al., 2003). First, online mentoring provides access to scientists even when students are located in isolated environments (Garrison, 2011). Second, Ensher et al. (2013) declared online mentoring “levels the playing field” by equalizing the status of all participants and preventing the unavoidable awkwardness students feel when third party “experts” enter the classroom. Reduced anxiety about partnering with scientists allows students the freedom to follow their natural desire “to feel connected to significant individuals” (Vallerand & Ratelle, 2002, p. 48). Third, online mentoring extends contact between scientists and students past the “one-time visit” status that Pekar and Dolan (2012) reported was typical of scientist-student interactions. Through asynchronous venues, students and scientists can communicate on a regular and on-going basis at their own conveniences, anytime and anywhere. Regardless of the nature of the project, time is a necessary commodity if online mentor-mentee relationships are to evolve into productive scientific partnerships (Sadler et al., 2010). Time is particularly important for establishing strong social presences in successful online relationships.

Social Presence

Social presence is a concept derived from the Community of Inquiry (CoI) framework (Garrison, 2011). Garrison (2011) defined a community of inquiry as “a group of individuals who collaboratively engage in purposeful critical discourse and reflection to construct personal meaning and confirm mutual understanding” (p. 15). Communities of inquiry include three interdependent parts: social presence, cognitive presence, and teaching presence. Specifically, social presence is “the ability of participants to identify with a group, communicate purposefully in a trusting environment, and develop personal and affective relationships progressively by way of projecting their individual personalities” (Garrison, 2011, p. 23). In academic contexts, social presence is achieved by more than mere social interactions. Social presence is achieved within a “climate that supports and encourages probing questions, skepticism, and the contribution of explanatory ideas” (Garrison, 2011, p. 32). Social presence implies a mix in interpersonal communication, cohesive communication, and open communication (Akyol & Garrison, 2008). Although these three types of communication occur throughout the duration of an online relationship, Garrison (2011) indicated interpersonal connections typically occur first and set the tone for future interactions. Open communication pushes and drives the purposeful “academic” conversations. Cohesive communication unifies the group and sustains the relationship. Together, these types of communication promote social adhesion, serve as ways to build group identity, and foster problem-solving interests among group participants (Akyol & Garrison, 2008).

Motivating Students in Science

Modern learning theories recognize affective constructs, including motivation, as central to learning and deserving of much more than peripheral consideration. Science education

researchers, however, often overlook motivation research in favor of cognitive studies (Koballa & Glynn, 2007). Motivation deserves more than peripheral consideration because motivated students *want to learn* and *believe they can learn*, two critical factors contributing to the development of deeper learning outcomes (Patrick & Middleton, 2002). When students are motivated, regardless of the domain, they perform better, experience more positive emotions, and enjoy the school experience (Deci, Vallerand, Pelletier, & Ryan, 1991). Teachers successful in promoting student motivation in science, therefore, would lead their students to apply more effort in learning science, which then naturally would lead to deeper understanding of essential science concepts (NRC, 2012). While motivational practices are diverse, some specific applications in science classrooms have been shown to be more effective than others in promoting positive student outcomes.

Providing opportunities for students to collaborate with others, especially when combined with online technology integration, is a motivational practice that effectively enhances science education. For example, Patrick and Middleton (2002) observed that group work and hands-on cooperative experiments led to positive student outcomes and better attitudes in science classrooms. With the addition of technology, Garrison (2011) learned collaboration with others via asynchronous venues was beneficial for some students because they were less intimidated and felt more freedom than when in face-to-face classrooms. Other research has confirmed online environments promoted greater autonomy, increased intimacy, and improved communication between participants (Ensher et al., 2003).

Interestingly, asynchronous online communication contexts can promote greater engagement than face-to-face contexts (Ensher et al., 2003). According to Ensher et al. (2003), without the pressures of physical presence, many students became more comfortable with the

online format (i.e., developed greater social presence) and engaged in more intellectual risk-taking. Additionally, the added wait time with asynchronous communication can lead to longer reflection on responses and recruitment of additional cognitive faculties (Garrison, 2011). These findings indicate online environments can be constructed to promote motivation leading to greater engagement and self-regulated learning.

While measuring motivation is difficult, particularly in online contexts, self-determination theory (SDT; Deci & Ryan, 1985) is a useful theoretical framework for explaining strong relationships between computer supported collaborative learning (CSCL) and student motivation. SDT is an organismic-dialectic theory postulating people look for supportive social contexts in an effort to obtain the basic psychological needs of autonomy, competence, and relatedness (Ryan & Deci, 2002). SDT defines these needs as follows: (1) autonomy – desire to regulate and control their own behavior; (2) competence – desire to engage in challenging tasks and experience some effectance; and (3) relatedness – desire to seek attachments and experience feelings of belonging and connection (Deci & Ryan, 2000). When online environments fulfill the basic psychological needs, CSCL environments can become motivating to learners. A successful CSCL environment, *PlantingScience*, was evaluated in this study using SDT.

Context for the Current Study

PlantingScience (PS) is an innovative, blended curriculum developed by the Botanical Society of America (BSA). Used internationally by over 11,000 students since 2005, PS provides advanced technology tools and supports to mix scientific inquiry, classroom instruction, and online mentoring by practicing scientists as students learn plant biology concepts within the context of contemporary middle and high school science classrooms. Students working in teams of 2-4 individuals design and carry out their own three- to ten-week long inquiry-based

experiments related to plant biology. Specific topics include seed germination (i.e., *The Wonder of Seeds*), photosynthesis (i.e., *The Power of Sunlight*), and sexual reproduction and alternation of generations (i.e., *C-Ferns in the Open*), among several others.

Many facets of PS mimic authentic scientific inquiry as outlined by Chinn and Malhotra (2002). For example, students generate original research questions originating from introductory "immersion experiences" with complex systems of variables. They then plan and implement their own analytical procedures and make observations leading to evidence-based conclusions. Furthermore, students often transform their observations to other data formats (e.g., graphs, presentations, drawings, spreadsheets, reports, etc.) and share them with others on the website.

Perhaps one of the leading reasons why PS has achieved success as an authentic scientific inquiry program is the incorporation of scientists as mentors who partner with student-teams for the duration of the inquiry projects. Over 900 professional scientists and science graduate students worldwide have volunteered for the program. These professionals provide key feedback to student-teams, often requiring students to clarify and defend their research questions, experimental designs, analytical methods, results, and conclusions. Using the language of Chinn and Malhotra (2002), PS can be viewed as a program providing scientist-mentors who help students engage in science more authentically by identifying potential flaws in student experiments and urging students to use evidence-based reasoning.

The scientists never physically visit the classroom. Instead, the PS website serves as an extension of the classroom, allowing student-teams and scientist-mentors to communicate in an asynchronous blog. The dialogues are archived on the PS website and are publically available (<http://www.plantingscience.org>). Additionally, student-teams communicate with scientists (and the public) by posting journals, photographs, spreadsheets, and other relevant inquiry-related

data to their own website page. Scientists view students' uploaded products and communicate with their assigned student inquiry teams to get “snapshots” of what they are doing in the classroom in order to provide appropriate mentoring. In 2011, PS received the prestigious SPORE Award (acronym for Science Prize for Online Resources in Education) from the American Association for the Advancement of Science (AAAS) for its technology innovation and successful student engagement (Hemingway, Dahl, Haufler, & Stuessy, 2011). PS combines student-scientist partnerships with online mentoring in an effort to improve scientific awareness, increase science classroom experience, and promote scientific proficiency. In the *Science* article announcing the award, PS developers noted:

Talking online with a scientist is exciting and motivating to students....The personal connection with an online mentor also holds promise for inspiring individual students. There is power in the collective commitment and expertise of scientist-school partnerships to efficiently raise engaging collaborative science learning to a national scale. (Hemingway et al., 2011, p. 1536)

In PS, online scientist-mentors provide students with a component of authentic science rarely mimicked in K-12 science classrooms. In the current study, seventh grade students in 10 student-teams partnered with scientists for six weeks to complete projects in the *Wonder of Seeds* module during a recent fall semester. We examined the interactions of scientists and students in each student-team. Each student-team generated their own primary research question, which guided their scientific inquiries to investigate the effects of differing soils and watering regimens on seed germination, for example, or to investigate the effects of different light sources on phototropism or seedling growth rates. With scientist-mentor participation, students designed experiments to test their research predictions. They reported their progress to their scientist-

mentors via the asynchronous blog on the *PlantingScience* website. Most students posted to the website during class time, although they did not post every class period due to time constraints. Scientists responded at their conveniences, with wait times between students and scientists varying from the same day to over one month. Most students and scientists, however, responded to each other's comments within three days. A example exchange between a scientist and student-team is included in Table 1.

Insert Table 1 About Here

Justification for the Current Study

Over the last several years, the national push for greater science achievement has placed new emphasis on student motivation (Koballa & Glynn, 2007). With its emphasis on the social context, SDT is a powerful tool for evaluating the effectiveness of social environments in different types of contexts. In particular, Chen & Jang (2010) stated online academic environments are especially suited to SDT studies, as online learning requires flexibility and choice (i.e., autonomy), technical skills (i.e., competence), and social interaction (i.e., relatedness). Within science learning contexts, online technology can afford scientists from all over the world the opportunity to partner with students in even the most geographically isolated school classrooms. Practicing scientists interacting with students could promote higher scientific literacy, greater science engagement, and improved student motivation in science. When providing the proper motivational support, scientists can potentially add immense value to the classroom science experience. As PS integrates technology, mentoring, and collaborative science, this unique learning environment provides a rich context for studying motivational

support.

Purpose of the Study

The purpose of this multiple case study was to investigate the motivational aspects of the interactions between student-teams and their scientist-mentors within the *PlantingScience* online environment. This project was designed to address a void in our understanding of the relationship between motivational support provided in an online mentoring environment and student engagement in inquiry. The study is unique in that it centers specifically on motivational support as provided by scientists in an online context. We used SDT as the theoretical framework for guiding the design of the investigation, expecting that we might find evidence linking increased inquiry participation in students with increased motivational support from scientist-mentors. According to SDT, adults who play significant roles in students' lives can promote increased student motivation (Deci et al., 1991). While significant adults in students' lives are traditionally parents, teachers, or coaches, participation in PS brings new significant adults into the academic lives of students—scientist-mentors who join student-teams for collaborative inquiry projects, thus providing an ideal "test bed" for investigating relationships between online mentoring and students' inquiry engagement.

The objectives of this study were to: (1) identify and describe the types of online motivational support provided by scientists as they mentored students' classroom inquiry projects; and (2) investigate potential associations of this support with the quality of students' engagement in scientific inquiry. According to Sadler et al. (2010), "finer grain" analyses, like the current study, can significantly improve science education in that they provide specific feedback on *why* certain partnership arrangements work as opposed to more generalized studies that just determine *if* partnerships work.

Methods

Research Design

We used a multiple-case replication design for this study (Yin, 2009). In specific parts of the analysis, we grouped cases using an extreme group comparison strategy (Chase, 1964). By reporting on both individual cases and replicate groupings, we were able to provide specific descriptions of cases and determine some associations between scientist-mentors' motivational support and student-team inquiry engagement. The units of analysis (i.e., cases) for this study were 10 student-teams taught collectively by one science teacher in two classes. Each team was partnered with one scientist volunteer assigned by the BSA to mentor one or more student-teams. All students designed inquiries related to the PS seed germination unit, *The Wonder of Seeds*.

SDT served as the theoretical framework for the study, which employed methods of quantifying qualitative data according to Chi (1997). Using SDT, we developed a motivational support rubric (see *Analysis* section for full description).

Sample

Student-teams. We purposively selected 10 student-teams (i.e., cases) composed of seventh graders enrolled in two different science sections in a rural public school located in the southwestern region of the United States. The rural school district enrolled 430 K-12 students. The teacher reported that approximately 65-70% of students in the district were from low socioeconomic households and some students' families lacked transportation and rarely if ever ventured out of the community. As few students had ever interacted with scientists face-to-face, this rural district provided an ideal setting for evaluating online scientist mentoring.

While these 10 cases provided an intriguing geographical context for study, we pre-screened the sample to ensure adequate student participation and inquiry engagement levels,

essentials in addressing the research questions posed for the study. Student participation and inquiry engagement levels in the 10 cases were compared to engagement levels in a baseline study of 263 PS student-teams (Peterson, 2012). Table 2 shows a comparison of participation levels (as indicated by number of posts in the dialogues) and inquiry engagement levels (as measured by the Online Elements of Inquiry Checklist—see *Methods-Measures* section for description) between student-teams in the current study and the comparison group. Levels of participation and engagement in the current study were deemed adequate to proceed with the study.

Insert Table 2 About Here

All student-teams in the current study worked on the same PS module under the direction of the same experienced teacher. Student-team members were novice inquiry learners, having had no previous experiences in scientific inquiry and only one collaborative group experience in learning science. Before beginning the PS project, the teacher familiarized students with the PS website and allowed students to list several classmates with whom they would like to work. From students' lists, the teacher chose the members for each student team, assuring that at least one classmate in the group had appeared on another team member's list. In her selection of students for group membership, the teacher also tried to balance the group's distribution with her knowledge about each student's strengths and skills (PS Teacher, 2012). Five student-teams with three to four students on each team were formed from each of two different class sections, making a total of 10 student-teams.

The two class sections met during consecutive class periods in the same lecture and laboratory classrooms. As a result of shared facilities and the small school culture, all 10 student-teams had opportunities to share ideas, methods, and results. In addition, the PS website design promoted productive participation between groups within and between the two class sections.

Scientist-mentors. Nine research scientists from across the U.S. served as mentors for the 10 student-teams (by chance, the BSA program assigned one scientist-mentor to two different teams in our study). Three scientists were professors, four were graduate students, and two worked in private industry. The scientists specialized in different botanical fields including plant genetics, plant ecology, plant physiology, and cellular biology. Additionally, the scientists had varying levels of experience with online mentoring, ranging from no experience to seven semesters of PS-specific mentoring. Information about each scientist's interests and background was available on the PS website for all to see, including students engaged in projects during any semester.

Teacher. The teacher in the study had taught science in rural middle and high schools for 25 years. She earned a master's degree in science education from a large state university five years before she received professional training specifically to assist her in implementing PS in her classroom. The BSA, with support from the NSF, provided the training. She attended three different PS summer workshops and followed each one of them with a PS implementation during the school year. The teacher's expertise and previous experiences with inquiry-based learning from her graduate work and continued refinement in the classroom with PS made the choice of her classes for this study even more appealing, as ongoing research studies examining teachers' implementation and orchestration of the PS inquiry environment have indicated great variability

in teacher's abilities to handle the difficult and complex PS environment (Scogin, Stuessy, Ozturk, & Peterson, 2013).

Measures

Motivational support. In this study, motivational support was operationally defined as scientist-mentors' words, phrases, thought segments, or textual expressions of emotions (e.g., capitalization, emoticons, exclamation points, etc.) appearing in the online dialogue with their student-inquiry teams, providing evidence of acknowledgement of and/or support for their team's autonomy, competence, and relatedness. Specifically for this study, we designed a motivational support rubric using a two-stage process. First, we explored SDT and social presence theory literature to identify valid indicators applicable to text-only learning environments. Second, we pilot-tested the rubric on sample scientist-mentor/student-team dialogues to assure that the indicators identified from the literature were relevant when applied to the context of the PS online dialogue. The research team negotiated a final motivational support rubric to include specific indicators of motivational support likely to be provided by scientist-mentors within the three SDT categories of autonomy, competence, and relatedness.

Autonomy support. Autonomy support is defined as “the degree to which [socializing agents] encourage independent problem solving, choice, and participation in decisions” (Grolnick & Ryan, 1989, p. 144). While behaviors supportive of autonomy are well defined in SDT literature, we found identification of text-only supports for autonomy to be particularly challenging. After careful consideration, we chose five indicators as evidence of scientist-mentors' autonomy support in online asynchronous dialogues. The five indicators included: (1) providing or acknowledging student-team choice (Deci et al., 1996; Reeve, 2002); (2) acknowledging student-team ownership/control of the project (Reeve et al., 2004; Ryan & Deci,

2002); (3) using autonomy supportive phraseology (i.e., not controlling language; Deci et al., 1996); (4) acknowledging negative student-team comments or outcomes (Deci & Moller, 2005; Reeve, Deci, & Ryan, 2004); and (5) providing a rationale for some aspect of science in general or the inquiry experiment in particular (Deci, Eghari, Patrick, & Leone, 1994; Reeve, 2002; Reeve et al., 2004). Autonomy supportive indicators with verbatim exemplary segments from the dialogues are included in Table 3.

Insert Table 3 About Here

Competence support. In educational contexts, instructional leaders provide competence support by giving attention to students and providing feedback/explanations that challenge students without offering definitive solutions (Newman, 2008). In the online PS context, we used three indicators of scientist-mentors' competence support. The three indicators included: (1) asking content or process questions specifically relevant to the inquiry project that provided challenges for the students, thereby supporting competence (Elliot, McGregor, & Thrash, 2002; NRC, 2012; Reeve et al., 2004; also see Sinatra and Taasoobshirazi, 2011, who stated environments promoting reflection and critical thinking are also competence-supporting); (2) offering explanations, typically in response to student-team questions (Ryan & Deci, 2000a, 2002; as well as Reeve, 2002, who discovered timely feedback as contributing to competence); and (3) providing positive feedback specifically related to student-teams' actions or statements (Deci & Ryan, 2002; Ryan & Deci, 2002; and Reeve et al., 2004, who further differentiated feedback to be competence-enhancing when it was tied to students' specific activities rather than

more general in nature). Table 4 contains verbatim examples of competence-supporting segments from the dialogues.

Insert Table 4 About Here

Relatedness support. "Relatedness involves developing secure and satisfying connections with others in one's social milieu" (Deci et al., 1991, p. 327). In PS, the relationship between the scientist-mentors and their student-teams evolved over the course of the students' inquiry projects, thus providing an ongoing context supporting growth in relatedness.

Social presence theory (Garrison, 2011) informed our framework for evaluating relatedness support. In particular, interpersonal, open, and cohesive communication categories were adopted from Garrison (2011) and used as indicators of relatedness support. Garrison stated that interpersonal communication, including self-disclosure, humor, and affective expressions (e.g., exclamation points and emoticons), sets the tone for participation in virtual environments. In comparison, open communication establishes trust between the online participants and involves reciprocity, acceptance, and inclusiveness. Open communication is the most "academic" of the three kinds of social presence communication. Furthermore, open communication includes inviting further participation and elaboration, complimenting previous contributions, expressing agreement, and recognizing previous contributions to the online discussion. Finally, in Garrison's estimation, cohesive communication is the goal of an online community: "It is cohesion that sustains the commitment and purpose of a community of inquiry, particularly in an e-learning group separated by time and space" (Garrison, 2011, p. 29).

References by name and team, and phatic or social conversation characterize cohesive communication.

In our construction of the motivational support rubric, we made several minor changes to Garrison's (2011) framework to enhance its applicability within the context of PS scientist-mentor/student-team dialogues. We settled on three indicators to evaluate interpersonal communication: (1) affective expression, (2) use of humor, and (3) self-disclosure. We used three indicators to determine cohesive communication: (1) inclusive language, (2) use of salutations, greetings, or phatics, and (3) use of personal names. Finally, we decided on four indicators to determine open communication: (1) asking questions or inviting participation, (2) complimenting and expressing appreciation, (3) expressing agreement, and (4) making references to previous student-team posts. Table 5 includes exemplary relatedness-supportive segments from the student-team/scientist-mentor dialogues.

Insert Table 5 About Here

Student inquiry engagement. We chose student inquiry engagement as the outcome variable in this study. With new standards (e.g., NGSS) calling for increased student engagement in authentic scientific practices, we deemed this outcome as applicable and useful to the goals of science education. Student inquiry engagement was measured using the Online Elements of Inquiry Checklist (OEIC; Table 6) developed by Peterson and Stuessy (2011) for assessing inquiry engagement in online environments and specifically for assessing engagement in PS. The OEIC is grounded in established inquiry literature and has been established as a valid and reliable instrument for assessing online inquiry engagement (Peterson, 2012; Peterson & Stuessy,

2011). Additionally, the items in the OEIC closely mirror the eight desirable scientific practices outlined in the NGSS.

Insert Table 6 About Here

The OEIC divides scientific inquiry into eight phases: (a) *Immersion*, (b) *Research Question*, (c) *Prediction*, (d) *Experimental Design and Procedures*, (e) *Observations*, (f) *Analysis and Results*, (g) *Conclusions and Explanations*, and (h) *Future Research and Implications*. A total of 40 elements distributed within each of the eight phases further characterize the extent to which students demonstrate successful engagement in the phase. We applied the instrument to all online evidence confirming that a student-team had successfully engaged in each of the single elements subsumed within each phase of the inquiry. We calculated percentages of phase completion using the number of elements successfully completed against the total possible number of elements within the phase. These percentages served as the outcome variables in this study.

Data Sources and Collection

The PS website contains many collection areas for uploaded data. For example, the “Research Information” section contains student-teams’ research question, research predictions, experimental design, and research conclusions (Figure 1). Additionally, journals (e.g., word processor files), data files (e.g., spreadsheet files), final presentation files (e.g., PowerPoint files), and images (e.g., photographs) are found in the “Project Data” section. We also consulted reflection memos completed by the teacher after the projects were completed to help describe the

context of the study from the classroom perspective (PS Teacher, 2012). The PS website also archives the dialogues between student-teams and scientist-mentors via the asynchronous blog in the “Conversations” section (Figure 1). The dialogues contain typed comments by students and scientist-mentors throughout the students' engagement in the inquiry. The dialogues were used as the data source for determining the motivation support provided by scientist-mentors. Data sources for determining student-teams' inquiry engagement included the dialogues as well, but also included evidence from student-teams' products (e.g., journals, charts, written reports) uploaded to the PS website.

Insert Figure 1 About Here

Validity

Construct validity was established on several levels as recommended for case research by Yin (2009). First, both instruments used in this study (i.e., motivational support rubric and OEIC) were based on well-established research literature. Second, specific terms and concepts (e.g., autonomy support) were operationally defined using theoretical grounding. These definitions were supplemented with low inference descriptors (i.e., verbatim examples) as recommended by Johnson (1997; see Tables 3-5). Third, multiple data sources generated independently by student-teams and scientist-mentors were used in the study.

Internal validity was also established as recommended by Yin (2009) for case study research. First, SDT, an established motivation theory, served as the theoretical framework for the study. Second, mixed methods (i.e., multiple analytic techniques) were used to evaluate the data and draw conclusions. Third, alternative explanations (i.e., rival hypotheses) for the final

results were considered (see *Discussion* section). Fourth, a predicted relationship between motivational support and student inquiry engagement was compared to empirical results from this study (i.e., pattern matching). Fifth, literal replicates (i.e., multiple cases) were included in each extreme grouping for specific parts of the analysis.

Analysis

We measured motivational support by quantifying the verbal dialogues (Chi, 1997) using an exploratory sequential mixed methods design (Creswell & Plano Clark, 2011). In the first phase, we qualitatively coded all scientist-mentor comments in the 10 dialogues using the motivational support rubric. The dialogue for each case, as well as codes and indicators from the rubric, were entered into Dedoose 4.5.95, an online mixed methods analytical software. We used a deductive coding approach (Miles, Huberman, & Saldaña, 2014) with pre-determined indicators from the motivational support rubric.

Coding the scientists' dialogues was particularly challenging for several of the reasons appearing in Strijbos, Martens, Prins, and Jochems (2006). The dialogues were both asynchronous and occurred over long periods of time, thereby adding to their fragmented nature. In addition, the fact that PS students worked in teams yet had the ability to post as individuals on the PS website presented coding challenges. These challenges made it difficult to establish an *a priori* method of segmentation.

According to Chi (1997), a “searching rather than segmenting” (p. 12) approach can be used in situations where spontaneous occurrences of the phenomena in question are typical (e.g., Chi, Bassok, Lewis, Reimann, and Glaser, 1989). Accordingly, we utilized a coding procedure originally developed for semi-structured interviews by Campbell, Quincy, Osserman, and Pederson (2013). The process developed by Campbell et al. (2013) provided a way to segment

the transcripts using the expertise of the most knowledgeable analyst as advocated by Krippendorff (2004). Campbell et al.'s coding process was developed to address the lack of standardized procedures for determining appropriate units of analysis for complex transcripts as pointed out by Hruschka et al. (2004) and Kurasaki (2000).

The lead researcher (i.e., the most knowledgeable motivational support researcher on the team) identified meaningful units of analysis as he searched and coded the text using the motivational support rubric. Simultaneous coding (i.e., co-occurring coding) was permissible, and only text corresponding to motivational support was coded. Next, codes were removed, and segments were presented to two naïve coders in segmented form in order to establish reliability (see next section). While Campbell et al. (2013) acknowledged this method might inflate inter-coder reliability, they asserted this approach “eliminates a potential source of confusion when comparing the coding of two or more coders especially when one is more knowledgeable than the rest” (p. 304). Figure 2 shows a coded excerpt from the current study using this methodology. After coding, we summed the numbers of codes for each motivational support category and calculated percentages.

Insert Figure 2 About Here

Reliability

In the current study, both a liberal index (percent agreement) and a conservative index (Fleiss's kappa; Fleiss, 1971) were used to determine reliability as per De Wever et al. (2006). The three coders applied the motivational support rubric to a random sample of 50 excerpts generated from the 10 cases. Percent agreement values between the three coders were as follows:

autonomy support – 85.3%; competence support – 88.9%; relatedness support – 85.3%. Fleiss' kappa values were as follows: autonomy support – 0.62; competence support – 0.72; relatedness support – 0.68. These values were indicative of a reliable rubric (Cicchetti, 1994; Landis & Koch, 1977; Lombard, Snyder-Duch, & Bracken, 2002), and the lead researcher coded the remaining dialogues from the 10 cases.

Research Questions and Predictions

Using a mixed methods approach, we sought to answer the following four research questions:

Question 1: How did autonomy and competence support differ between scientist-mentors across the 10 cases? What specific methods did scientist-mentors use to promote autonomy and competence in student-teams?

Question 2: How did scientist-mentors differ in the way they supported relatedness with their student-teams across the 10 cases? What specific types of communication did scientist-mentors use to establish social presence with their student-teams?

Question 3: Did an association exist between the motivational support student-teams received from scientist-mentors and subsequent student-team engagement in the inquiry cycle across the 10 cases?

Question 4: Using extreme group comparisons, what similarities and differences existed between highly engaged cases and less engaged cases? What similarities and differences existed between cases receiving high motivational support and cases receiving less motivational support?

Results

The purpose of this study was to evaluate online scientist-mentors' motivational support of student-teams in a rural school district and investigate the potential associations of this support

with students' inquiry engagement. Table 7 contains data about scientist-mentors' motivational support for all 10 cases. In most instances, cases 5 and 7 received the lowest amounts of motivational support while case 8 received the highest amount. Specifically, total motivational support varied from 31 total code segments in cases 5 and 7 to 132 code segments in case 8. On average, scientist-mentors provided 72 motivationally supportive assertions per project.

Autonomy supportive code segments varied from five in cases 5 and 7 to 32 in case 8 with an average of 14. Similarly, competence supportive code segments varied from seven in cases 5 and 7 to 37 in case 8 with an average of 18. Relatedness supportive code segments varied from 19 in cases 5 and 7 to 66 in case 2 (case 8 was a close second with 63) with an average of 40. These findings indicate a distinct “feast or famine” environment for student-teams in regard to the amount of motivational support they received from their scientist-mentors.

Insert Table 7 About Here

Based on the results in Table 7, we conducted a Kruskal-Wallis nonparametric ANOVA and discovered significant differences between the amounts of autonomy, competence, and relatedness supports ($H = 15.28, p < .01$). A series of nonparametric Mann-Whitney U follow-up tests with Bonferroni correction (Vogt, 2005) indicated relatedness support was significantly higher than both autonomy support ($U = 3, p < .01$) and competence support ($U = 12, p < .01$). Autonomy support and competence support levels did not differ significantly. All scientists (with the exception of case 4) showed similar patterns of motivational support, with some scientists providing support in higher quantities. The remaining results are organized and reported according to the four research questions driving the study.

Question 1: How did autonomy and competence support differ between scientist-mentors across the 10 cases? What specific methods did scientist-mentors use to promote autonomy and competence in student-teams?

Autonomy support. Table 8 contains raw counts, means, and standard deviations of autonomy supportive codes for each case. Overall, autonomy supportive codes ranged from 32 in case 8 to 5 in case 7, with an average of 14 codes. A Kruskal-Wallis test revealed significant differences between the types of autonomy support provided by scientists ($H = 21.15, p < .01$). Post-hoc using Mann-Whitney U with Bonferroni correction showed scientist-mentors used *Providing Choice* ($U = 7, p < .01$) and *Acknowledging Ownership* ($U = 4.5, p < .01$) significantly more often than *Acknowledging Negatives*. No other variables differed significantly.

Insert Table 8 About Here

Competence support. Table 9 contains raw counts, means, and standard deviations of competence supportive codes for each case. Overall, competence supportive codes ranged from 37 in case 8 to 7 in cases 5 and 7, with an average of 18 codes. A Kruskal-Wallis test revealed types of competence support differed significantly ($H = 12.077, p < .01$). The Mann-Whitney U -tests with Bonferroni correction uncovered that scientist-mentors used *Content/Process Questions* more often than *Positive Feedback* ($U = 6, p < .01$). No other significant differences were found.

The top three motivationally supportive scientist-mentors (cases 2, 8, and 10) most often used content and process questions to support competence (Table 9). From a qualitative perspective, scientist-mentors used these questions for a variety of reasons including: (1)

ascertaining background knowledge of the student-teams (e.g., “Have you learned about what types of nutrients plants require?” – case 10); (2) requiring students to clarify statements (e.g., “What size containers are you using to grow your plants?” – case 3); (3) asking students to justify decisions (e.g., “Why do you think the seeds will grow faster in potting soil?” – case 2); and (4) encouraging students to draw conclusions (e.g., “Can you think of another reason why plants grown under a heat lamp may turn out different than those grown under regular light bulbs?” – case 6).

Insert Table 9 About Here

Since relatedness support was measured using indicators informed by social presence theory, these differences were investigated as part of a separate research question.

Question 2: How did scientist-mentors differ in the way they supported relatedness with their student-teams across the 10 cases? What specific types of communication did scientist-mentors use to establish social presence with their student-teams?

Table 10 contains raw counts, means, and standard deviations of interpersonal, cohesive, and open communication codes for all 10 cases. Overall, relatedness supportive codes ranged from 19 in cases 5 and 7 to 66 in case 2, with an average of 40 codes. Specifically, interpersonal communication codes ranged from three in case 7 to 16 in case 8, with an average of 10. Cohesive communication codes ranged from nine in case 5 to 29 in case 2, with an average of 17. Open communication ranged from four in cases 5, 7, and 9 to 25 in case 2, with an average of 12. A Kruskal-Wallis *U*-test revealed no significant differences between the use of interpersonal, cohesive, and open communication.

Insert Table 10 About Here

However, Kruskal-Wallis test results indicated scientists differed significantly in how they provided interpersonal communication support ($H = 18.802, p < .01$). The Mann Whitney U -test with Bonferroni correction revealed *Affective Expression* was used more often than either *Humor* ($U = 0.5, p < .01$) or *Self-Disclosure* ($U = 3.5, p < .01$). This fact is not surprising as affective expression is the easiest of the three to share in a text-based medium. Inclusion of the keystrokes “:),” symbolic of a smiley face, is a simple affective expression.

Scientist-mentors also used cohesive communication in significantly differing amounts ($H = 16.157, p < .01$). *Use of Names* was more commonly used than both *Salutations/Greetings/Phatics* ($U = 12, p < .01$) and *Inclusive Language* ($U = 2, p < .01$), probably due to easy inclusion. Use of *Salutations/Greetings/Phatics* and *Inclusive Language* did not differ significantly.

In regard to open communication, scientist-mentors used the various techniques in significantly different amounts ($H = 19.158, p < .01$). Specifically, *Questioning/Inviting Participation* ($U = 3.5, p < .01$), *Complimenting/Expressing Appreciation* ($U = 15.5, p < .01$), and *References to Previous Posts* ($U = 5.5, p < .01$) were used more often than *Expressing Agreement* (48% of all codes in the open communication category were related to *Questioning/Inviting Participation*). Scientist-mentors were sometimes general in their invitation, stating, “I can’t wait to hear more. Let me know if you have any questions” (case 10

scientist-mentor). In other instances, invitations were much more specific and probed for feedback about particular results from the experiment, such as the comment by the case 2 scientist-mentor: “Have you observed your plants this week? I’m curious about how they’re doing—but especially wondering if the perlite seeds have germinated or not.”

Student response times to these questions and invitations varied. In both of the examples from the preceding paragraph, student-teams responded the next day. Other invitations, such as “Let me know what you think about these questions” (case 9 scientist-mentor) were not answered until one full week later. In an extreme case, the scientist-mentor in case 7 never received a response related to a posed question. Interestingly, the case 7 student-team had the lowest OEIC score of all 10 cases, indicating little engagement in the inquiry process.

Question 3: Did an association exist between the motivational support student-teams received from scientist-mentors and subsequent student-team engagement in the inquiry cycle across the 10 cases?

Student-team engagement in the inquiry cycle was measured using the 40 elements of the OEIC (see Table 6). Relative percentages of student engagement in the eight inquiry phases were calculated, and Table 11 shows student-team OEIC scores by case. Overall OEIC scores ranged from 8 (case 7) to 85 (case 10), with an average of 53. Student-teams averaged the highest OEIC score during the *Prediction* phase. The lowest mean scores were recorded during the *Experimental Design and Procedures* phase.

Insert Table 11 About Here

Spearman's rho was calculated to determine potential associations between scientist-mentor motivational support and student-team inquiry engagement. The Spearman's rho between total motivational support and overall OEIC scores was 0.444 ($p = .20$). When comparing overall OEIC scores with each motivational category, the following results were obtained: autonomy support – 0.165 ($p = .65$); competence support – 0.508 ($p = .13$); relatedness support – 0.609 ($p = .06$). Spearman's rho was also calculated for each element of inquiry (Table 12). Autonomy support showed no significant associations with student engagement in any inquiry phase, a finding contrary to SDT. A significant and moderate association was found between competence support and the *Research Question* phase. Relatedness support was highly associated with the *Research Question* phase and moderately associated with the *Observations* phase.

Insert Table 12 About Here

Question 4: Using extreme group comparison, what similarities and differences existed between highly engaged cases and less engaged cases? What similarities and differences existed between cases receiving high motivational support and cases receiving less motivational support?

For this particular question, we used an extreme group comparison strategy (Chase, 1964) to replicate cases and create disparate groupings for mixed methods comparison. According to Chase (1964), extreme group comparison is useful when comparing high and low scorers on a given characteristic using some other characteristic. As a form of triangulation, we formed two different extreme groupings based on two different criteria: scientist-mentor motivational support

(as determined by the motivational support rubric) and student inquiry engagement (as determined by the OEIC).

In the first grouping, we divided the 10 cases based on total scientist-mentor motivational support as determined by the number of motivationally supportive codes. The top three and bottom three cases in regard to total scientist-mentor motivational support were grouped together. Table 13 provides information about the specific cases (i.e., replicates) included in this first grouping. We identified these cases as highest motivational support (HMS) and lowest motivational support (LMS).

Insert Table 13 About Here

In the second grouping, we divided the 10 cases based on student inquiry engagement as determined by total OEIC scores. The top three and bottom three cases in regard to total OEIC scores were grouped together. Table 13 provides information about the specific cases (i.e., replicates) included in this second grouping. We identified these cases as highest engagement (HE) and lowest engagement (LE).

Quantitative Results From Extreme Group Comparisons

From the first grouping, we compared HMS and LMS cases in regard to student-team inquiry engagement in the eight phases of inquiry. HMS student-teams showed engagement in 68% of the items on the OEIC compared to only 41% for LMS student-teams. Mann-Whitney U -test results revealed this difference was significant ($U = 9.5, p = .021$). Specifically, with the exception of *Experimental Design and Procedures*, HMS case student-teams showed higher engagement in all phases of the inquiry cycle when compared to the LMS cases. The greatest

differentiations (> 30 percentage points) in engagement between the HMS cases and LMS cases were in *Immersion*, *Research Question*, *Observations*, *Conclusions and Explanations*, and *Future Research and Implications*. The overall trend of HMS cases engaging in inquiry at higher levels was apparent.

One puzzling finding was the discovery that student-teams across the board did not engage well in the *Experimental Design & Procedures* phase of inquiry (both HMS and LMS groups scored only 33 on the OEIC). However, this trend has been documented in other research about PS (Peterson, 2012). The Peterson (2012) work revealed that even though scientist-mentors emphasized experimental design more often than any other stage of inquiry, student-teams consistently showed less evidence of engagement in this phase than in most other inquiry phases. Also, in the current study, the lack of engagement in *Experimental Design & Procedures* may be a limitation posed by the purpose of the OEIC; the OEIC only evaluates information posted on the PS website, thereby providing no way of recording students' actual in-class engagement in inquiry. While engagement in this phase may be occurring at a much higher level in actual classroom practice, students must make online references to their classroom engagement in order for the OEIC to detect evidence of that engagement.

From our second grouping, we compared HE and LE cases in regard to the amount and type of motivational support they received from scientist-mentors (Table 14). Overall, HE cases received more motivational autonomy, competence, and relatedness support than LE cases. The greatest differentiations were found in competence and relatedness support. Overall, HE cases received almost twice as much motivational support as LE cases. The association between higher engagement and more motivational support was also apparent from this group comparison.

Insert Table 14 About Here

Trends in the Cases

The information in Table 13 revealed trends that formed the basis of our subsequent qualitative comparisons. First, cases 2 and 10 were both HMS and HE cases, indicating they received the highest amounts of scientist-mentor motivational support and exhibited the highest inquiry engagement. We referred to these two cases as *Exemplary*. A professor of plant genetics with no previous PS mentoring experience mentored case 2. A graduate student in cellular biology with four semesters of PS mentoring experience mentored case 10.

In contrast to the *Exemplary* cases, cases 5 and 7 were included as LMS and LE cases, indicative of the lowest amounts of scientist-mentor motivational support and least amount of inquiry engagement. We referred to these two cases as *Unsatisfactory*. Case 5 was mentored by a graduate student in plant physiology with no prior experience mentoring in PS. Case 7 was mentored by a graduate student in cellular biology with two semesters of PS mentoring experience.

The *Exemplary* and *Unsatisfactory* cases followed the pattern we expected to see in this study. SDT postulates that motivation occurs on a continuum (Ryan & Deci, 2000a), and differing contextual support levels have effects on overall motivation (Ryan & Deci, 2002). Therefore, SDT predicts that students who receive more motivational support will be more engaged (Deci & Ryan, 2000). Likewise, less motivational support can lead to less engagement. According to our expectations, when scientist-mentors' motivational support increased (as

measured by the motivational support rubric), we predicted an associated increase in student inquiry engagement (as measured by the OEIC). Both the *Exemplary* and *Unsatisfactory* cases supported this prediction.

However, case 9 was unique because it was included in the LMS and HE groups. In other words, the student-team received low amounts of scientist-mentor motivational support yet exhibited high inquiry engagement. We referred to this case as *Atypical* and will look at it more closely later. A graduate student in plant physiology with no previous PS mentoring experience mentored case 9.

Qualitative Comparison of *Exemplary* and *Unsatisfactory* Cases

The scientist-mentors in the *Exemplary* cases were similar in how they provided motivational support to their student-teams. Both scientist-mentors set the stage for building relationships with students from the first post. Table 15 contains verbatim first posts from both the *Exemplary* and *Unsatisfactory* cases. Both *Exemplary* scientist-mentors opened their posts with affective expressions. They also expressed excitement about partnering with students in the inquiry projects (an example of relatedness support) and tried to engage learners with questions. In addition, the scientist-mentor in case 2 provided specific information indicating knowledge about what the student-teams had already done in class. While this may seem trivial, it indicates the scientist-mentor communicated with the teacher before the project began (which shows special interest). Both *Exemplary* case mentors also showed a personal interest in their student-teams, with the case 2 mentor asking, “What were the most interesting things that you noticed about seeds?” and the case 10 mentor asking, “What is your favorite plant?” Both *Exemplary* mentors also shared personal information (i.e., self-disclosure) in this important “first contact” and signed off using their first names (i.e., cohesive communication).

Insert Table 15 About Here

The *Unsatisfactory* cases' (5 and 7) scientist-mentors also opened their first posts with affective expressions and closed their posts with first names. They also expressed excitement about working with students. However, neither *Unsatisfactory* case scientist-mentor asked any questions to either support competence or promote future engagement (i.e., support relatedness). The case 7 scientist-mentor did little to support motivation (or anything else) in the first post.

As the projects matured, further differences were noted between the *Exemplary* and *Unsatisfactory* cases. Student-teams in both of the *Exemplary* cases seemed to develop a comfortable relationship with their scientist-mentors. Student-teams in these cases included their scientist-mentors as part of the research team, often asking the scientist-mentors for help. For example, the students in case 2 asked, "We are not sure how much water to put in it, can you help us?" In these cases, students considered advice from the mentors and made some decisions based on the feedback. In another example, the case 10 students commented to their scientist-mentor, "Thank you for all the info, it really helped us come to the decision of comparing the rate of germination." Over the course of the project, these *Exemplary* student-teams seemed to look forward to hearing from their mentors and seriously considered any advice they received.

As we examined the discourse, we also noticed that when *Exemplary* student-teams asked questions, their scientist-mentors spoke directly and relevantly to those questions, treating them with importance. In one instance, the scientist-mentor in case 2 responded to a student-team request with the following:

A few of you said that you're curious about whether seeds grow faster in soil or without. Can you tell me a little more about how you and [teacher's name] grew the seeds that you looked at last week?....Some of you also wondered whether a seed could sprout or keep growing after you cut it in half. This made me wonder three things: (1) What kinds of seeds did you observe last week?, (2) Did you...cut open any of the seeds?..., (3) What do you all think might happen if you cut a seed in half?

This response exudes thought, concern, and a desire for continued discourse on the matter. In contrast, the responses of the scientist-mentor from case 5 (see Table 15) were factual “answers” to questions posed by students and provided no connections to the project at hand, indicating little thought about the project. In another instance from the *Unsatisfactory* case dialogues, the case 7 student-team expressed interest in looking at the effects of varying sugar concentrations on seed germination and plant growth. In a response the next day, the case 7 scientist-mentor asked, “Do you have any ideas about what you might like to focus on?” and never indicated she had read the students’ previous comments. This lack of relatedness support could have affected the students’ motivation to engage their scientist-mentor in future discussions. As a matter of fact, after this particular exchange, the student-team in case 7 did not post for nine days. When they did post, it was to inform the scientist-mentor they had already started their experiment.

Qualitative Results for the *Atypical* Case

The discourse for Case 9, the *Atypical* case, started out with both students and the scientist-mentor engaged in ongoing conversation. The scientist-mentor’s opening post was rich, containing a salutation, affective expression, self-disclosure, inclusive language, acknowledgment of ownership/interest, use of names, a rationale, and references to previous student posts. The scientist-mentor encouraged students and asked many questions to bolster

both competence and relatedness. Early on, the student-team responded to comments by the scientist-mentor in positive ways such as, “Thank you very much for the recommendations. We are using the same water conditions for each. Oh yeah, and thank you for reminding me about the lighting conditions,” and “Thank you for the suggestions. We do not have them in strong sunlight, but they are doing great.”

One of the most interesting aspects of this conversation was the revelation by one member of the student-team that, “I have been working on the experiment at my house.” While it is impossible to ascertain from the dialogues if this was an accurate statement, its plausibility may help explain why student inquiry engagement levels for this case were high when scientist-mentor motivational support was low. Working on the project at home is indicative of intrinsic interest on the part of the student(s). As a result, perhaps the student(s) in this team were not affected by the overall lack of outside motivational support from the scientist-mentor.

The puzzling results from this *Atypical* case may also point to a potential shortcoming of our measure of motivational support. Since the motivational support rubric is based on quantitative counts, it may sometimes fail to capture the essence of specific, targeted, high quality motivational support. While the amount of motivational support was low, based on our measure, qualitative analysis of the dialogue indicates that members of the student-team may have developed a sense of relatedness with the scientist-mentor anyway. For example, one of the last student-team comments for case 9 was as follows:

Dear [Scientist-mentor name]. Hi, I am happy that I got a chance to work on here with you as my mentor. I just want to say THANK YOU!!! :) I really appreciate all of your suggestions. We were so happy to have you following us on our project. I’m sad that we

aren't doing our project any more, but once again I just want to say thank you, thank you, thank you very much. Sincerely, your "science buddy" :) [Student name] <3

In this particular case, our results were confounded but also speak to the value of looking at the data from multiple perspectives and using different techniques and methodologies.

Discussion

Our study was designed to evaluate associations between online scientist-mentor motivational support and student inquiry engagement. Based on SDT, we predicted that increased motivational support from online scientist-mentors would associate with greater student-team inquiry engagement. While not claiming causality, this multiple-case replication study provides strong evidence supporting the existence of a relationship between the two variables. However, we uncovered several interesting and unexpected aberrations providing valuable insight into the complex world of online mentoring, thereby helping us outline strategies for supporting students' motivational resources in online environments.

Challenges and Benefits of Using Scientists as Online Mentors

Our analyses indicated that scientists-mentors provided vastly different *amounts* of motivational support to their student-teams. While explicit reasons for this disparity in motivational support cannot be determined from this study, we carefully offer some insights. Scientists involved in PS are typically research scientists and not educators. They volunteer their time as mentors in classroom science projects. Other than some mentoring-related training resources on the PS website, most scientists are not trained to facilitate online learning and/or establish social presence in virtual environments. Additionally, they are not trained in motivational theory or self-determination. This study indicates some scientists are quite adept at providing motivational support through online communication in spite of these circumstances.

However, predictions that student engagement will automatically increase with indiscriminate recruiting and placement of scientists in classrooms, whether virtual or face-to-face, are shortsighted at best.

In order to make online programs like PS more effective and equitable for all participants, preparing online mentors to deliver motivational support seems warranted. Previous research documents the challenges of facilitating online learning environments (Rovai, 2007). As previous PS-specific research shows, orchestrating the complexities of a blended environment that incorporates inquiry with technology is extremely complex, even for seasoned educators (Scogin et al., 2013). Scientists, and all other online mentors, need training in providing appreciable choice, engaging students in challenging conversation, and establishing connectedness between people through social presence because doing so seems to make a difference. Based on the scientist-mentors' varying propensities to provide motivational support in this study, the skills needed to support vibrant and engaging online environments are not necessarily intuitive and may need explicit attention.

Previous research on PS revealed that training teachers to orchestrate the complex PS environment has positive impacts on student inquiry engagement (Peterson, 2012). If training has an impact on teachers, it stands to reason that additional training for scientist-mentors might also increase student inquiry engagement. Research by Pekar and Dolan (2012) revealed that scientists operating in classroom partnerships typically occupy different roles from classroom teachers. In the Pekar and Dolan study, scientists provided conceptual and epistemological support, while teachers necessarily made sure students had access to the new knowledge. In other words, teachers were "better prepared and positioned" to offer pedagogical support, while scientists were more equipped to integrate scientific terminology, relate issues of the nature of

science, and make real-world connections to science. These findings show the potential importance and value of using trained scientists as online mentors who, as Edelson (1998) might say, provide authenticity not often experienced in science classrooms.

The Roles of Autonomy, Competence, and Relatedness Supports in Online Mentoring

The correlational analysis (Table 12) revealed no significant associations of autonomy support with student engagement at any inquiry stage in this study. In addition, one of the HMS cases (case 10) actually had an autonomy support count less than the mean of all 10 cases (see Table 7). The lack of statistical evidence of a relationship between autonomy support and student engagement was unexpected. SDT research claims that autonomy support is the most important factor in self-determined motivation (Deci & Ryan, 2000). Entering the study, we thought autonomy support by scientist-mentors would be a critical component leading to increased student inquiry engagement. We offer a few thoughts on the lack of evidence supporting this prediction.

Online environments are naturally autonomous because of the transaction distance involved between participants (Moore, 1993). Perhaps autonomy supportive statements by scientist-mentors made little difference to students because students already felt in control of the process and could ultimately decide whether to respond to scientists' comments, and if so, when. Also, it is conceivable that autonomy support is not as important in online mentoring relationships such as PS. Students, knowing that online mentors are not in a position to enforce demands and/or change grades, may feel autonomous regardless of how an online mentor expresses autonomy support through text. Or, once scientists expressed autonomy support and students felt comfortable and "in control," maybe future autonomy-supporting expressions had little additive effect. The role of autonomy support in online text-based contexts definitely needs

more research to determine how or if autonomy support differs in online versus face-to-face contexts.

While a relationship between autonomy support and inquiry engagement was not discovered in this study, both competence and relatedness support showed some associations with student inquiry engagement, particularly during the *Research Question* phase of inquiry (see Table 12). The *Research Question* phase is the first opportunity in an inquiry cycle for students to think about their own independent projects, and it makes sense that “feeling” support, either intellectually (i.e., competence) or relationally (i.e., relatedness) from scientist-mentors could influence students to engage in this initial process at a deeper level. Remember, these students were inquiry novices, so perhaps getting motivationally supportive feedback from scientist-mentors at this stage was particularly encouraging and influenced engagement. Relatedness support also showed a strong association with the *Observations* phase of inquiry. We will discuss the relationship between these elements in the following section.

Importance of Relatedness Support in Online Mentoring

With the aid of online technology, students and scientists involved in programs like PS develop relationships that could play a significant role in the future success of online/blended science education initiatives. Although SDT posits autonomy and competence as the two most important factors in promoting self-determined motivation (Deci & Ryan, 2000), relatedness plays a special role in school environments. Since students rarely feel autonomous at school and are often either overwhelmed or unchallenged by the curriculum, school-related activities are typically not intrinsically motivating (Ratelle, Guay, Vallerand, Larose, & Senecal, 2007). Under these conditions, a strong relationship (i.e., established relatedness) with a significant other has been shown to stimulate student motivation (Koestner & Losier, 2002). Referred to as

Organismic Integration Theory (OIT), this applicable SDT sub-theory states, “Whereas relatedness is less central than the other two needs for maintaining intrinsic motivation, it is very much central for promoting internalization” (Ryan & Deci, 2002, p. 19).

Internalization occurs when individuals begin to personally endorse behaviors or activities that were once extrinsically motivated (Deci & Ryan, 2000). In PS, perhaps scientists serve as the “significant other” for students. Maybe the motivational support they provided is the critical factor explaining why PS engages students. Other research in SDT supports this conclusion (Ryan & Deci, 2000a). Also, research showing that students develop stronger identities as science learners through forged relationships with scientists seems relevant to this line of thinking (Bryan et al., 2011).

Although not explicitly part of our analysis, we could not help but notice how many student-teams responded to their scientist-mentors in ways indicative of relatedness. In many of the dialogues, students began by self-disclosing in friendly and conversant manners. Statements such as “I love rock and roll and country music” (case 2), “I love baseball” (case 4), and “I love horses and rodeo” (case 10) were fairly common among student-teams. Other disclosures were more personal, such as this case 1 revelation, “I also have a very good lab partner. Her name is [student’s name]. I didn’t think that we would get along but we do very well.” Other students talked about botany preferences, such as, “My [favorite tree] is the pecan tree because I love eating the pecans!” (case 10).

In other instances, student-teams expressed desires to know more about the scientists. “We are curious to know what you look like. Could you please post a picture?” (case 2). After the scientist-mentor posted the picture, the student-team responded, “Thank you. :D Now we know who we are talking to.” In another case, students asked about the scientist’s work

environment. “Do you work with other people? About how many?” (case 1). These comments indicated that the students had a desire to connect with scientists on a level beyond simply partnering together to complete a school project.

Once projects got into full swing, we also noted comments indicating that student-teams desired feedback from their scientist-mentors. A case 1 student, in the midst of a week-long online discussion with classmates and the scientist-mentor about a potential research question, wrote to the scientist-mentor, “What I really want to know is what you think, and why? I can’t wait to hear back from you.” Another student in the same case commented to the scientist-mentor, “Hey, it’s nice to hear back from you. How are you doing?” These types of comments characterized student-teams eager for support from scientists and equally eager for conversation beyond simple project dialogue.

As projects came to a close, several student-teams expressed appreciation to the scientist-mentors and indicated the experience was worthwhile. “Thank you so much for all of your hard work and time!! It means so much to us! I’m so glad that we got the chance to do this exciting experiment!!” (case 8). “Thank you for all of your help. If it wasn’t for you, we wouldn’t know what to do” (case 4). In one instance, a student from case 1 expressed how much he/she related to the scientist-mentor’s personality. “You are a good guide. You like to get into things and ask a lot of things. I am a person who likes to ask questions myself.” These comments, along with the associations of relatedness supportive comments with student inquiry engagement, provide evidence that students valued the relationships they forged with the scientists.

As mentioned previously, a high association was found between relatedness support and student engagement during the *Observations* phase of inquiry (Table 12). Based on the OEIC (Table 6), *Observations* include students sharing their data and research on the online platform.

The dialogues indicated that this was a particularly important part of the process as students and scientists exchanged information back and forth regarding observations. Scientist-mentors used open communication strategies (see Table 5) most often to get students to share observations. For example, sometimes scientist-mentors asked questions and invited participation from student-teams: “Looking forward to hearing more about your observations!” (case 2 scientist-mentor). “Any cool observations?” (case 10 scientist-mentor). Scientist-mentors also expressed appreciation for student-teams when they shared observations, with comments such as “Thanks for all your updates and posting the pictures of your measurements and observations” (case 8 scientist-mentor), “Thanks for posting the pictures” (case 3 scientist-mentor), “Thanks for the photos – they look great!” (case 6 scientist-mentor), and “I see that you’ve added a new picture! Thanks!” (case 2 scientist-mentor). Student-teams were also eager to share observations, often telling scientist-mentors they were about to post updated pictures, data charts, or other observational data. “Look at our pictures sometimes and hopefully today I will be able to post new pictures” (case 9 student-team).

While relatedness between scientists and students may be a key factor in the success of PS, more research needs to be done regarding educative online relationships. Simply communicating with students over the Internet is not enough. Social presence is a delicate dynamic, and while many scientist-mentors successfully engaged students, others struggled to create a strong social presence. For example, the student-team in case 3 (an LE case) became frustrated with what they perceived as lagging responses and asked their scientist-mentor, “Will you put up a picture of you and reply?”

Evidence Against Behaviorism

Adopting a behavioral view of motivation is tempting. As educators, we may think

providing the proper environmental conditions guarantees motivated behavior. On the contrary, SDT postulates that internalized motivation is fully autonomous and self-directed (Ryan & Deci, 2002). The results of this study provided an unexpected way for us to show evidence that motivational support should not be viewed as a "reward" or "necessary factor" in assuring students' engagement in inquiry.

As mentioned in the *Methods* section, by chance the BSA assigned the same scientist-mentor to two different cases in our study (cases 5 and 9). The amount of motivational support provided by this mentor was similar in both cases. Each case was part of the LMS grouping, indicating this scientist-mentor provided motivational support in the lower tertile for this study. However, the student outcomes for these two cases were very different. Case 5 was part of the *Unsatisfactory* cases, while case 9 was the *Atypical* case. In other words, case 5 students did not engage at high levels while case 9 scored in the upper tertile of the OEIC, indicative of high student inquiry engagement.

These two cases provide evidence that in education, students ultimately make the decision to participate and engage. As educators and mentors, we are obliged to provide the most supporting environments possible, and we should be willing and equipped to provide autonomy, competence, and relatedness support. However, what students choose to do under these conditions is ultimately their decision. After all, the ultimate expression of autonomy (i.e., self-determination) is the decision of whether to engage in a given activity or walk away. We should provide all students with motivational support, but realize that an amotivated response is still possible. This realization makes research on internalization (i.e., increased motivation in previously amotivating situations) through increased relatedness that much more critical to the future of education in general and online educational initiatives in particular.

Alternative Explanations and Limitations

In case study research, considering alternative explanations for the observed phenomena is critical for establishing validity (Yin, 2009). While the associations found in this study were evident, the aforementioned differences in cases 5 and 9 reiterate the fact that scientist-mentor motivational support is not the only possible factor contributing to differences in student-team inquiry engagement. Research diligence demands alternative explorations be addressed.

Typically in a study such as this one, differences in teacher quality would be explored since teachers have a great impact on learning and, without a doubt, influence how deeply their respective students go in an inquiry project. However, all 10 student-teams in this study had the same teacher, thereby eliminating teacher quality as a primary reason for observed differences in student inquiry engagement.

Another alternative explanation we explored was dialogue quantity. Perhaps specific motivationally supportive statements by scientist-mentors did not have as much impact on students as general voluminous online conversation. While scientist-mentors in the HMS cases did post more often than LMS cases (10 posts versus 5 posts per case), concurrent research on the social discourse patterns in the student-scientist dialogues in these same 10 cases did not find any association between student inquiry engagement levels and dialogue quantity (Perkins & Stuessy, 2013). Additionally, Spearman's rho showed no significant correlation between number of scientists' posts and student OEIC scores ($p = .147$).

Yet another potential alternative explanation deals with the members within each of the student-groups. Group membership was determined by the teacher, who acknowledged students'

choices with whom to work as a major determinant of group membership while also making some efforts to populate groups with students of diverse abilities. No efforts were made to randomly select members for groups. Inequalities in group membership could be a viable limitation to the study. This alternative explanation warrants consideration when designing future online motivational support studies.

An additional alternative explanation relates to the importance of immersion in the inquiry process. HMS cases provided more evidence of engagement in the *Immersion* phase of inquiry. Perhaps these teams were better “grounded” in the inquiry, thus sustaining their interests in their inquiry projects over the course of the project, without regard to the amount of motivational support they received. Findings in the Peterson (2012) study support this alternative explanation. In that study, “exemplary” student-teams in PS engaged at higher levels during immersion than “average” student-teams. Although all student-teams in the current study were provided with the same opportunities for immersion in the classroom (e.g., they had the same teacher and resources), online evidence of students’ engagement varied considerably. The current study design precludes differentiating between the effects of high-immersion engagement and online scientist-mentor motivational support.

In regard to OEIC calculations, our analysis was limited to the material posted on the website by the student-teams. The teacher noted in her personal reflections that students often struggled in their attempts to elaborate their ideas online (PS Teacher, 2012). Also, students sometimes failed to remember their online audience and assumed their activities and conversations in class, even if not posted, were somehow accessible to their online scientist-mentors (and ultimately the researchers). Ensuring students participate fully in the online component represents another orchestration challenge inherent in complex blended learning

environments. In the context of this research, students' failures to post certain products could have led to underestimation of student-team inquiry engagement, particularly as OEIC scores were dependent on student-team products/dialogues uploaded and archived on the PS website.

Finally, as we purposively selected our sample and the overall inquiry engagement levels were high, generalizability to other situations is limited. We also recognize that our analysis was limited to scientist-mentor motivational comments and did not consider student-team responses in the dialogues. The coding and analysis of student-team comments is a fertile ground for future analyses.

Implications and Future Direction

As online/blended learning grows in popularity and practice, research leading to the development of engaging learning environments under these conditions becomes more critical. The challenges faced by educators and learners, especially in text-only environments, are fundamentally different than in face-to-face formats. Establishing relationships and motivating learners is not as intuitive in text-only conditions. The research in this study provides a first step in establishing a connection between motivational aspects of online scientist-mentoring and student inquiry engagement. While association does not imply causality, this study at least confirms a typical co-occurrence between two fundamental components of the PS blended learning environment: mentor motivational support and student inquiry engagement.

SDT provides a time-tested theoretical framework for evaluating motivation in learning environments. Techniques to support learner autonomy, competence, and relatedness (through the establishment of social presence) can be important to the future success or failure of online learning. For many nontraditional students and/or rural students, online or blended learning environments provide access to high quality educational experiences, without the constraints of

accessibility and time. As new online programs are developed, this research provides theory-driven information on how to promote student motivation and engagement through online technology.

The findings in this study represent the “tip of the iceberg” when it comes to investigating motivationally supportive online mentoring environments. Future experimental studies in which groups of online mentors receiving training in motivational support are compared to control groups with no training would provide critical follow-up research. Also, determining how student-teams’ needs change over the inquiry cycle and how scientist-mentors’ motivational support best meets these changing needs would be a fruitful next step for online mentoring research.

Conclusion

The current study provides evidence of a general positive association between online motivational support and student inquiry engagement. As scientist-mentors provided more motivational support to the student-teams (especially relatedness support), we detected a general pattern of greater student-team inquiry engagement. However, scientist-mentors differed in the amounts of motivational support they provided and the way in which they provided support. This finding reinforces the notion that online contexts are difficult to orchestrate and online mentors need training in motivational support and establishing social presence.

Moreover, this study demonstrates how scientific engagement can be enhanced through participation in innovative programs such as *PlantingScience*. Seeing student comments such as “I love this experiment,” “We are excited!,” and “I’m glad that we got the chance to do this experiment!” are encouraging, particularly in science, a subject that has been associated with student apathy and disinterest in recent years. As existing online learning programs are modified

and new online opportunities are created, curriculum developers should consider and integrate motivationally supportive principles into the learning environments. Concerted efforts to support student autonomy, competence, and relatedness through social presence provide nurturing online environments that can lead to higher engagement. Finally, but no less important, this study provides evidence that scientists have the potential to make greater impacts on society through direct involvement in educational endeavors.

Acknowledgements

We wish to acknowledge the students and scientist-mentors who participated in these projects. Special thanks are also in order for the teacher who volunteered her classes for analysis in this study. We also acknowledge the National Science Foundation (NSF Award 07-33280) and the Department of Teaching, Learning and Culture at Texas A&M University. Any opinions, findings, or conclusions expressed in this report are those of the authors and do not necessarily reflect the views of the funding agency or Texas A&M University.

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List of Figures

Figure 1. Example screenshot of a *PlantingScience* student-team project page. All projects are available publically through the PS website (www.plantingscience.org).

Figure 2. Example coding segment from Case 10 scientist-mentor.

The Smartical Particals!!!!!! :) / Marion Jr/Sr High School / MPH_S13_W08

School Level: Middle School/Jr High

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Research Information

Research Question

If we change the sunlight from bright to no light, then will the seeds germinate?

Research Predictions

If we try to grow the plant in the dark, It will then grow slower.

Experimental Design

1. Getting the Materials- Alfalfa seeds, Styrofoam bowls, cup, soil, fresh water, spoon and a box.
Each person gets 2 bowls. Each bowls will have 3 seeds each. We will have four bowls in a box and close it. Than four bowls will be in a box but won't be closed
2. Our control group will have the seeds on the bottom and will be in the box .Our experimental group will have the seeds on the bottom and will be in a closed box
3. We will water it 20ml a day
4. We will use alfalfa seeds and will be recording our data everyday.
We will fill the soil in the bowls with the same amount. The seeds will be put on top then we will sprinkle some more soil on top. Everything else has to be the same besides the brightness of the light. Our control group will be in a box that is open and closed box will be a light barley reaching the plant. We will use the Google Spreadsheet

Research Conclusions

We wanted to know if alfalfa seeds would plant better in light(control group) or dark(experimental group)? We figured out that the plants grow better in dark. Both experiments were very close. Our experimental group had an average of 51cm. We predicted that the experimental group would grow slower. We were wrong. Our dark light,(experimental group) grew more than the light,(control group). Our control group had a average of 43cm. Our experimental group grew way faster than our control group. We figured out that our seeds germinated better in the Dark. Alfalfa seeds could be grown in the light or dark it would still grow just fine.

Conversations – use this space to communicate about this project

Only logged in users are allowed to comment. [register/log in](#)

April 15, 2013 | 1:59 PM | [Dr. Catrina Adams](#)

Farewell and Best Wishes

As this research project is now in the final stages of wrapping-up, we wish to thank everyone who participated in this inquiry; the students, mentors, teachers and others behind the scenes. We appreciate all of your efforts and contributions to this online learning community.

Scientific exploration is a process of discovery that can be fun! There are many unanswered questions about plants just waiting for new scientists to consider, investigate, and share.

Please come back and visit the PlantingScience Research Gallery Archive anytime to view this project in the future. You can search the Archive by key word, team name, topic, or school name.

Good bye for now.

Warm regards,
The PlantingScience team

Research Team Profile

The Smartical Particals!!!!!! :) / Marion Jr/Sr High School / MPH_S13_W08

Project Data

Our Uploaded Journals:

Our Uploaded Data Files:

- [GrowthofAlfalfaSeedseffectedbylights-Sheet1.pdf \(32.41k\)](#)

Our Uploaded Final Presentation Files:

- [PlantingSciencePresentationSmarticalPa \(64.36k\)](#)

Images:

The starting of the box that has the lid open

Video:

Table 1

Example Asynchronous Blog Dialogue Between Scientist-Mentor and Student-Team (Case 10)

October 10 8:37 PM (Scientist/Mentor)

Hypothesis

You have written a great hypothesis and I can't wait to find out what your results are. How will you measure growth rate? Are you sure that growth of your plants in different soils will be due only to the soil type? Do you [know] the terms we use for these different types of variables? Can't wait to hear more!
[Scientist's Name]

October 11 11:11 AM (Student-Team Member)

~Ms.[Scientist's Name],

Today we are starting our project!!!! We will be measuring our plants growth by centimeters. We are positive that the plants in the soil will have a more rapid growth rate, because of the nutrients that are in it.

~ [Student-team Name] :)) (~

~ [Students' Names](: ~

Thanks for all of the advice [sic]!!!!!!!!!

October 13 10:22 AM (Scientist/Mentor)

Starting Project

Hey guys!

I like your explanation of your hypothesis. Have you learned about what types of nutrients plants require? I bet you could do a quick google search to find out.

How are your plants doing so far? Any cool observations?

~[Scientist's Name]

October 13 11:05 AM (Student-Team Member)

Ms. [Scientist's Name]~

Hey well our project is kinda over, since ALL of our seeds have germinated!!!!!!!!!!!!!! It didn't take very long for the beans to grow a root and be classified in the germinating category!!!!

~[Student-team Name]:)~

~[Students' Names]~ (:

October 13 11:06 AM (Student-Team Member)

all of our plants have grown since we have planted them! they all have a little root coming out of the bottom of them.

~[Student Name] [Student-team Name]~

October 13 11:14 AM (Student-Team Member)

nutrients

Ms.[Scientist's Name] ~

This is what we found on the internet about what nutrients mung beans need ...

However, once the seed begins to sprout and deplete this small storage of nutrients, it requires suitable soil to encourage continued growth. Mung bean sprouts prefer soils with pH levels between 6.2 and 7.2, as well as adequate amounts of sulfur, magnesium phosphorus and potassium. Fertile soils that contain a rich blend of sand and loam provide essential nutrients for healthy growth.

Sincerely [sic],

~[Student-team Name] :)) ~

[Students' Names]

October 17 8:47 AM (Scientist/Mentor)

Conclusions?

Hi Team [Student-team Name]!

I see you have uploaded a whole bunch of pictures and you tell me that your project is over. The last steps to every experiment is to draw conclusions and come up with future experiments. What sort of things did you learn from your experiment? Is there anything you would do differently next time?

Happy Concluding.

~[Scientist's Name]

October 19 11:32 AM (Student-Team Member)

Our Conclusions (So Far !!!)

Howdy Ms. [Scientist's Name] ~

Well our hypotesis [sic] was true at least up to today. The soil has grown AMAZING, the shortest root is 7 in.! I guess you can say we know what nutrients the soil has and the others don't. We were really suprised [sic] to see that the saw dust has actually grown some leaves and steams [sic].

Some of the seeds in the silt have MOLD ON THEM, HOW GROSS IS THAT ? When we saw that we all said EWWW!!! Our seeds have really grown quite FAST [We] were really suprised [sic] that over the weekend with no water and light that our plants sproted [sic] right up.

THANKS FOR ALL OF YOUR HELP!!!!!!!!!!!!!!

! [Student-team Name]:))

~ [Students' Names]~

Table 2

Comparison of Participation and Student Inquiry Engagement Levels Between Current Study and XXXX (2012) Study

	Current Study (<i>n</i> = 10)	XXXX (2012) Study (<i>n</i> = 263)
<u>Student-Team Participation Measures</u>		
<i>Mean</i> number of posts by student-teams	20.4	8.5
<i>SD</i> of posts by student-teams	6.3	6.4
<i>Minimum</i> number of posts by student-teams	15	0
<i>Maximum</i> number of posts by student-teams	33	44
<u>Student-Team Inquiry Engagement Measures</u>		
Immersion	60	33
Research Question	68	59
Prediction	73	64
Experimental Design and Procedures	30	34
Observations	63	33
Analysis and Results	45	45
Conclusions and Explanations	44	24
Future Research and Implications	50	14

Table 3

Autonomy Supportive Verbatim Statements From Scientist-Mentor/Student-Team Dialogues

Providing or acknowledging student-team choice

Let me know when you've chosen one question to focus on, and I can help you with experimental design.
[Case 8 Scientist-mentor]

Acknowledging student-team ownership/control of the project

I have a few ideas and questions that may help in running your experiment. [Case 9 Scientist-mentor]

Autonomy supportive phraseology (i.e., not controlling)

You might want to research some plants that you want to work with (e.g. corn, beans, peas) and what types of minerals and nutrients they need to grow. [Case 4 Scientist-mentor]

Acknowledging negative student-team comments or outcomes

Unfortunately scientists deal with failed experiments all too often. [Case 4 Scientist-mentor]

Providing a rationale for some aspect of science or the project

A lab notebook updated daily is an important part of a scientist's job. It is important to have accurate and detailed notes - of both things that work and things that don't work. This way you can look for patterns and try to figure out what is happening. [Case 1 Scientist-mentor]

Table 4

Competence Supportive Verbatim Statements From Scientist-Mentor/Student-Team Dialogues

Asking content or process questions specifically relevant to inquiry project

Why might one type of seed need a helicopter wing (maple seed) while another seed need to [be] really small (radish seed)? [Case 10 Scientist-mentor]

Offering explanations

Hi everyone, I am not surprised to hear about your results with the coke and vinegar. Let's think a bit about the properties of those two liquids. The Coke is something you like to drink because it tastes sweet. If you look on the label, you see that the sweetness comes from a type of sugar. Lots of things want to eat that sugar - including the mold and mildew that is growing on your seeds. The seeds don't need the sugar from the Coke, because they pack their own as starch in the seed to tide them over until they begin to photosynthesize to make more sugar on their own. Now that the fungus is established, it can start to kill the seeds by growing into them. This isn't a problem with the water, because it doesn't provide a good media for the fungus and it can't get established in the seeds. [Case 1 Scientist-mentor]

Providing positive feedback

I just noticed that you have now posted your research question and that you want to focus on the effect of vinegar on plant growth and that you are predicting that vinegar will decrease plant growth. That is a great start. [Case 3 Scientist-mentor]

Table 5

Relatedness Supportive Verbatim Statements From Scientist-Mentor/Student-Team Dialogues

INTERPERSONAL COMMUNICATION

Affective expression

I'm glad that you guys had fun working on your experiment! I hope you all learned a lot. Plants are really interesting systems to study. Good luck on your classes this year! :)

[Case 9 Scientist-mentor]

Use of humor

All scientists do this, even us old ones! [Case 8 Scientist-mentor]

Self-disclosure

Where do you live? I live in Nova Scotia which is on the east coast of Canada, just North east of Maine. Nova Scotia is like Maine in many respects. Fishing and forestry are important industries. In my area, the Annapolis Valley, agriculture is also important. We grow apples, grapes, blueberries, raspberries, strawberries, etc. Nova Scotia is in the Acadian Forest region. This is an area where the natural vegetation is a mixture of deciduous and evergreen trees. This time of year the leaves of the deciduous trees are turning color (red, orange, yellow) and the forest looks very pretty.2) What kind of music do you like? I like all kinds of music, but I especially like old rock and roll music from the 50's and 60's. I am afraid I don't know any rap music, but I do listen to it sometimes as my youngest daughter is a fan.

[Case 3 Scientist-mentor]

COHESIVE COMMUNICATION

Inclusive language

I'm glad that you're a part of the experiment as well! I can't wait to work with you more.

[Case 9 Scientist-mentor]

Salutations/greetings/phatics

It's been cool and rainy here lately. How is the weather in Texas? [Case 9 Scientist-mentor]

Use of Names

Hello Plant Rockers! Summer Rose, thanks for telling me which seeds you've looked at and how you sprouted the seeds last week. [Case 2 Scientist-mentor]

OPEN COMMUNICATION

Asking questions/inviting participation

Have you started your experiment yet? How is it going? Are all the seeds still alive? Have there been any surprises? [Case 8 Scientist-mentor]

Complimenting and appreciation

I appreciate you giving your project some thought and coming up with a question that intrigues you.

[Case 8 Scientist-mentor]

Expressing agreement

The numbering sounds like a good way to keep track of your seeds! [Case 2 Scientist-mentor]

References to previous posts

I just noticed that you have now posted your research question and that you want to focus on the effect of vinegar on plant growth and that you are predicting that vinegar will decrease plant growth. That is a great start. [Case 3 Scientist-mentor]

Table 6

Forty Items of the Online Elements of Inquiry Checklist (XXXX, 2012)

a. Immersion

Is there mention of information-gathering efforts that occurred before students posed their research questions?

Is there mention of prior knowledge or experiences that enabled the learners to question the relationship between variables?

b. Research Question

Is the research question appropriate for the context of the study?

Are variables of interest observable and/or measureable?

Is there explicit evidence that the research question is tied to prior knowledge or experience?

Is there evidence that the students chose their own research question?

Can the research question be answered within the scope and boundaries of the inquiry setting?

Is the research question logically linked to a prediction, hypothesis, or expectation?

If the question is causal in nature, is the research question testable through a scientific investigation?

If the question is causal, is a relationship between the variables the focus of the research question?

c. Prediction

Is there evidence that the learners have considered possible or probable outcomes to their investigation?

Is their evidence that a project outcome is based on prior knowledge or experience?

Is the predicted outcome reasonable in light of the research question that is being asked?

d. Experimental Design and Procedures

Did the research design enable the learners to answer the research question?

Is there evidence that students themselves developed research methods?

Is there a description of research methods in enough detail so that another research group could replicate them?

Did the learners mention confounding variables?

Are controls of variables mentioned?

Is there mention that the learners controlled for possible sources of error in their observation methods?

e. Observations

Is there evidence that research events were recorded?

Did the learners describe what they observed?

Are data tables included in the inquiry project?

Did the learners describe or discuss the data table(s)?

Did the learners provide visual displays of their data such as graphs, charts, or pictures?

Did the learners describe or discuss the visual displays?

Do the visual displays follow accepted conventions?

f. Analysis and Results

Did the learners mention patterns or trends in the data?

Did the learners compare data across multiple studies from other student groups?

Did the learners mention unexpected results?

Was the data used to answer the research question?

g. Conclusions and Explanations

Are the conclusions of the experiment connected to the data that was collected?

Are the conclusions consistent with the data that was collected?

Did the learners support ideas about causality with data?

Is there mention of alternative explanations?

Did the learners compare their results to other studies' results?

Did the learners discuss the limitations of their research?

Did the learners justify their conclusions using data?

Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?

h. Future Research and Implications

Did the learners discuss the implications of their study?

Is there mention of possible study revisions?

Table 7

Scientist-Mentor Motivational Code Segment Counts

Cases	SDT Category			Total Support
	Autonomy Support	Competence Support	Relatedness Support	
1	12	21	30	63
2	17	26	66	109
3	14	18	34	66
4	18	16	47	81
5	5	7	19	31
6	13	13	34	60
7	5	7	19	31
8	32	37	63	132
9	8	13	34	55
10	12	26	52	90
Total	136	184	398	718
<i>Mean</i>	13.6	18.4	39.8	71.8
<i>SD</i>	7.8	9.4	16.6	32.1

Table 8

Scientist-Mentor Autonomy Supportive Code Segment Counts

Cases	Autonomy Supportive Code Segments					Total Autonomy
	Providing Choice	Acknowledging Ownership	Supportive Words	Acknowledging Negatives	Providing Rationales	
1	3	3	2	0	4	12
2	5	7	3	0	2	17
3	4	7	3	0	0	14
4	2	6	4	2	4	18
5	1	2	1	1	0	5
6	4	5	4	0	0	13
7	4	1	0	0	0	5
8	9	13	4	3	3	32
9	1	4	0	0	3	8
10	5	4	2	0	1	12
Total	38	52	23	6	17	136
Mean	3.8	5.2	2.3	0.6	1.7	13.6
SD	2.3	3.4	1.6	1.1	1.7	7.8

Table 9

Scientist-Mentor Competence Supportive Code Segment Counts

Cases	Competence Supportive Code Segments			Total Competence
	Content/Process Questions	Offering Explanations	Positive Feedback	
1	12	8	1	21
2	21	2	3	26
3	8	7	3	18
4	3	11	2	16
5	3	4	0	7
6	6	5	2	13
7	6	0	1	7
8	21	11	5	37
9	7	4	2	13
10	20	2	4	26
Total	107	54	23	184
<i>Mean</i>	10.7	5.4	2.3	18.4
<i>SD</i>	7.3	3.8	1.5	9.4

Table 10

Scientist-Mentor Relatedness Supportive Code Segment Counts

Cases	Relatedness Supportive Code Segments			Total Relatedness
	Interpersonal Communication	Cohesive Communication	Open Communication	
1	9	10	11	30
2	12	29	25	66
3	10	12	12	34
4	12	21	14	47
5	6	9	4	19
6	7	12	15	34
7	3	12	4	19
8	16	27	20	63
9	14	16	4	34
10	12	25	15	52
Total	101	173	124	398
<i>Mean</i>	10.1	17.3	12.4	39.8
<i>SD</i>	3.9	7.5	7.0	16.6

Table 11

Percentages of Student-Team Inquiry Engagement

Inquiry stage	Cases										<i>Mean</i>	<i>SD</i>
	1	2	3	4	5	6	7	8	9	10		
<i>Immersion</i>	0	100	50	50	50	100	0	50	100	100	60.0	39.4
<i>Research Question</i>	75	100	38	88	63	50	13	75	75	100	67.7	27.6
<i>Prediction</i>	67	67	67	33	67	100	33	100	100	100	73.4	26.4
<i>Experimental Design</i>	50	33	0	0	33	50	17	0	50	67	30.0	24.6
<i>Observations</i>	57	86	71	71	57	57	0	57	71	100	62.7	26.3
<i>Analysis and Results</i>	25	25	25	50	75	75	0	50	50	75	45.0	25.8
<i>Conclusions</i>	63	63	13	50	25	63	0	50	50	63	44.0	23.1
<i>Future Research</i>	50	50	50	50	50	50	0	50	50	100	50.0	23.6
<i>Mean</i>	55.1	67.6	35.2	52.0	50.1	62.6	7.6	52.5	64.9	85.2	53.3	20.7
<i>SD</i>	24.6	28.7	25.2	25.8	16.9	21.4	12.3	28.1	22.0	16.7	14.4	

Note: Numbers represent percentage of OEIC completion for the elements within each inquiry stage. The overall mean OEIC score was calculated on the basis of total number of elements within the entire checklist without reference to scores on individual stages.

Table 12

Spearman's Rho Correlations Between Scientist-Mentor Motivational Support and Student-Team Inquiry Engagement

Inquiry stage	Motivational Support Category		
	Autonomy Support	Competence Support	Relatedness Support
<i>Immersion</i>	.170	.204	.573
<i>Research Question</i>	.406	.685*	.738*
<i>Prediction</i>	.098	.342	.362
<i>Experimental Design</i>	-.492	-.032	-.092
<i>Observations</i>	.331	.500	.679*
<i>Analysis and Results</i>	-.032	-.032	.121
<i>Conclusions</i>	.293	.555	.508
<i>Future Research</i>	.235	.552	.514

Note. * $p < .05$

Table 13

Breakdown of Extreme Group Comparisons Based on Amount of Scientist-Mentor Motivational Support (First Grouping) and Student-Team Inquiry Engagement (Second Grouping)

	First Grouping		Second Grouping	
	Highest Scientist Motivational Support (HMS)	Lowest Scientist Motivational Support (LMS)	Highest Student Inquiry Engagement (HE)	Lowest Student Inquiry Engagement (LE)
Cases	Case 2 ^{***} Case 8 Case 10 ^{***}	Case 5 [*] Case 7 [*] Case 9 ^{**}	Case 2 ^{***} Case 9 ^{**} Case 10 ^{***}	Case 3 Case 5 [*] Case 7 [*]
Mean	110.3	39.0	72.6	30.9
SD	21.0	13.9	10.8	24.2
Note: Mean and SD based on number of motivationally supportive code segments of each case in grouping			Note: Mean and SD based on total OEIC score of each case in grouping	
Note: ***Exemplary cases; **Atypical case; *Unsatisfactory cases				

Table 14

Number of Motivationally Supportive Coding Segments (as determined by motivational support rubric) and Amount of Scientist-Mentor Motivational Support by Case Grouping

Type of Motivational Support	Extreme Groups (based on student inquiry engagement)	
	HE Cases (<i>n</i> = 3)	LE Cases (<i>n</i> = 3)
<i>Autonomy Support</i>	37	24
<i>Competence Support</i>	65	32
<i>Relatedness Support</i>	152	72
<i>Total Motivational Support</i>	254	128

Table 15

Verbatim "First Posts" from Exemplary and Unsatisfactory Cases

EXEMPLARY CASES

Case 2

Hello [Team Name]!

Thanks for telling me a little bit about yourselves. I have never been in a band, but I do mostly listen to rock music. I even sometimes listen to rock music while I'm studying plants in my laboratory! I'm excited to be working with you, too.

I work at [college], which is in [town]. Part of my job is to teach biology classes to college students. The other big part of my job is to work with college students to conduct experiments in my laboratory. Most of my research focuses on a part of the plant called the "shoot apical meristem" (SAM, for short). Have you heard of the SAM?

[Teacher's name] mentioned to me that last week you observed some germinating seeds. What were the most interesting things that you noticed about the seeds?

[First name of scientist-mentor]

Case 10

Hiya!

My name is [first name of scientist-mentor] and I will be your mentor for the next few weeks. I am super excited to find out what questions you will have for me.

Do you know what project you will be working on? What have you learned about plants? What is your favorite plant? Mine is the Sunflower.

~[First name of scientist-mentor]

UNSATISFACTORY CASES

Case 5

Hello All

Hope you all are doing well. I'm excited to work with you on your experiment!

@[student name]: Yes, all plants have structures in the seed. This link shows the major parts of the internal structure of seeds <http://www.landlearn.net.au/newsletter/2008term2/images/Seed-rotated.jpg>.

@[student name]: Yes seeds have an embryo inside, that's what the small plant comes from.

@[student name]: The seeds form inside the watermelon. A watermelon is like a apple or an orange. The seeds are inside the fruit where they develop into mature seeds. The actual part of the watermelon that you eat is the plants ovary. In some of these types of plants the purpose of the fruit is to attract animals which eat the fruit and its seeds and excrete them in feces in another location. This carries seeds to other areas for the plant to grow.

If you all have any other questions feel free to ask :)

[First name of scientist-mentor]

Case 7

Hello team!

Greetings! I can't wait to hear from you.

~[First name of scientist-mentor]