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Guiding Students' Scientific Practice: Distinct and Common Roles for Teachers and Scientists

Deniz Peker[1] **and Erin L. Dolan**[2]

Abstract

Many science education programs involve scientists in K-12 education to support students' engagement in scientific practices and learning science process skills and scientific epistemologies. Little research has studied the actions of scientists in classrooms or how scientists' actions may (or may not) supplement or complement the actions of teachers. In this descriptive study, we explore how teachers and scientists, working in pairs, guide high school students in the practice of scientific experimentation. In particular, we study the ways by which teachers and scientists act independently and in concert to guide students in designing and conducting biology experiments with unknown outcomes. We analyzed video recordings of classroom instruction in two different school settings, focusing on teachers' and scientists' acts as they are manifested through their language-in-use during face-to-face interactions with students. We argue that scientists and teachers act to support students in scientific experimentation in both distinct and common ways influenced by the particular teaching acts they perform and distinct authority roles they possess in the classroom (e.g., classroom authority vs. scientific authority).

Keywords

scientific practices, teacher-scientist partnership, laboratory science, learning communities, high school

Introduction

Educators, researchers, and policymakers alike have advocated for engaging students in science learning that resembles the authentic practices of scientists (American Association for the Advancement of Science, 1993; Edelson & Reiser, 2006; National Research Council [NRC], 1996, 2000; Next Generation Science Standards Lead States, 2013; Rutherford & Ahlgren, 1989). Authentic practices are considered rich contexts for developing students' skills within the domain of study as well as their understanding of its epistemology. Learning through scientific inquiry is often promoted because of its potential to engage students in authentic science practices. When students engage in scientific inquiry, they have opportunities to reason scientifically as they generate research questions, design inquiries, and explain and defend their results (NRC, 2000). Edelson and Reiser (2006) note that the pedagogical challenges of helping students handle the complexity of authentic practices are compounded by the practical challenges of implementation. Specifically, teachers may not have experience integrating scientific practices into their instruction and may not themselves have first-hand experience with these practices.

A number of science education initiatives aim to create social structures that support student engagement in authentic scientific practices by involving scientists in K-12 classroom activities. For example, the U.S. National Science Foundation's Graduate STEM Fellows in K-12 Education program supported long-term K-12 internships by STEM graduate students to improve their teaching and communication skills and bring their "practice into the K-12 classroom" (http://www.gk12.org). Similarly, the U.K. Royal Society's *Partnership Grants Scheme* provides support for school science projects that involve scientists (http://royalsociety.org/education/partnership), and the Australian *Scientists in Schools* program support long-term partnership between teachers and scientists (http://www.scientistsinschools.edu.au). At a more grassroots level, numerous programs have fostered collaborations between K-12 students and teachers and research scientists to collect, analyze, and make meaning of data (Dolan, 2008; Fougere, 1998; Lawless & Rock, 1998; Spencer, Huczek, & Muir, 1998; Tinker, 1997). Yet, little research has explored what scientists do to scaffold students as they engage in scientific practices, or the specific roles teachers and scientists play in helping students navigate an authentic problem space.

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In this descriptive study, we explore how teachers and scientists, working in pairs, guide students in the practice of scientific experimentation. In particular, we study the ways by which teachers and scientists act to guide students as they design and conduct biology experiments with unknown outcomes. We focus primarily on teachers' and scientists' acts as they are manifested through their language-in-use during face-to-face interactions with students (Bloome et al., 2008). We examine teachers' and scientists' talk as a communicative event rather than as a linguistic construct (Louwerse & Graesser, 2005) to identify how they support novices' authentic experimental practices. We document and characterize teachers' and scientists' actions by addressing the following research questions:

> **Research Question 1:** In what ways do teachers and scientists act to support students in scientific experimentation?
>
> **Research Question 2:** In what ways, if any, do the actions of teachers and scientists differ?

We argue that scientists and teachers support students in scientific experimentation in distinct and common ways influenced by the teaching acts they perform and their authority roles (e.g., classroom authority vs. scientific authority). We believe that this work lays a foundation for identifying relationships between particular teacher and scientist acts and specific student outcomes.

The inquiry context for this study is the Partnership for Research and Education in Plants (PREP). Through PREP, a teacher and a scientist guide groups of students in designing, conducting, and interpreting original experiments to yield insights into the function(s) of genes in the plant, *Arabidopsis thaliana*, which is investigated widely in plant biology. Students determine whether and how the plant's genotype affects its response to environmental stresses (e.g., drought, extreme soil pH, etc.). We characterize the ways in which teachers and scientists act to support students in determining research questions, selecting and controlling variables, planning procedures and measures, selecting analytical methods, conducting analyses, and interpreting results, a process we call "experimentation" for simplicity.

A number of studies have identified the roles that teachers assume in inquiry approaches to science teaching, including motivator, guide, researcher, modeler, and mentor (Crawford, 2000; Osborne & Freyberg, 1983). A much smaller body of literature about scientists' involvement in pre-college classroom activities consists primarily of program descriptions and advice from program developers (Dolan, Lally, Brooks, & Tax, 2008; Fougere, 1998; Lawless & Rock, 1998; Lally, Brooks, Tax, & Dolan, 2007; Siegel, Mlynarczyk-Evans, Brenner, & Nielsen, 2005; Spencer et al., 1998; Tinker, 1997; Trautmann & MaKinster, 2005). Research on these programs has focused on documenting student outcomes such as gains in achievement (Laursen, Liston, Thiry, & Graf, 2007) or interest in science (Bruce, Bruce, Conrad, & Huang, 1997; Sadler, Burgin, McKinney, & Ponjuan, 2010), or on changes in teachers' instructional practices or lack thereof (Laursen et al., 2007; Nelson, 2005). None of these studies has explored the specific actions of scientists in classrooms or the ways in which scientists may (or may not) offer instructional scaffolding that complements or supplements the scaffolding provided by teachers.

Theoretical Framework

PREP adheres to the principles of situated learning, which envisions learning as a "process of enculturation or individual participation in socially organized practices, through which specialized local knowledge, rituals, practices, and vocabulary are developed" (Hennessy, 1993, p. 2). This process is mediated "by social and intellectual supports" through which learners can see how knowledge and practices are used in authentic settings (Quintana, Shinn, Norris, & Soloway, 2006, p. 123). PREP serves as an authentic problem space for students' learning (Lally et al., 2007; Turvey & Shaw, 1995), while putting students in charge of identifying, at least in part, the focus and purpose of their investigations (Rahm, Miller, Hartley, & Moore, 2003; Roth, van Eijck, Reis, & Hsu, 2008). PREP involves students and teachers in the "ordinary practices of the culture" (Brown, Collins, & Duguid, 1989, p. 34) by using biological materials that are being generated and studied actively by the scientific community and by engaging in a community of practice that includes their scientist-collaborators (Collins, 2006; Lave & Wenger, 1991). Students' findings have been incorporated into science publications (e.g., Owens et al., 2008) and as preliminary results in grant proposals. Thus, during PREP, students have opportunities to learn both explicit and tacit knowledge and skills through practice that is guided by teachers and scientists (Collins, Brown, & Newman, 1989).

Because our interest was in identifying and characterizing the actions of scientists and teachers, we chose to utilize a frame proposed by Tharp and Gallimore (1988) and Tharp (1993) for characterizing the teaching acts that experts employ to assist learners' performance. The theory of teaching as assisted performance is grounded in the works of Vygotsky (1978) and Leont'ev (1981), which characterized student learning as a process of internalization, such that children move from social interaction to self-regulation as they learn to solve problems. Through this process, a more knowledgeable person helps a learner accomplish a task that the learner would otherwise be unable to accomplish (Reiser, 2004; Wood, Bruner, & Ross, 1976). Vygotsky (1978) called the gap between what a learner could accomplish alone versus with assistance the zone of proximal development (ZPD). Learning occurs first on a "social plane" through interaction between the learner and the assister, and then the plane is "internalized" to a "psychological plane," at which point the learner can perform independently. In this study, our interest is in identifying the actions of teachers and scientists that occur in the social plane as they assist students in experimentation.

According to the teaching as assisted performance framework (Tharp, 1993; Tharp & Gallimore, 1988), experts' acts can be categorized in the following ways:

> 1. *Modeling:* The offering of behavior for imitation. Modeling assists by giving the learner a standard for performance.
> 2. *Feedback:* The process of providing information about a performance as it compares to a standard. Feedback allows for comparison between actual performance and a particular standard, thus allowing for self-correction.
> 3. *Contingency management:* The application of the principles of reinforcement and punishment to behavior.
> 4. *Instructing:* A request for specific *action* that assists by indicating a correct response, providing clarity or information, or making decisions. Instructing is most useful when the learner can perform some segments of the task, but cannot yet analyze the entire performance or make judgments about the elements to choose.
> 5. *Questioning:* A request for *verbal* response that assists by producing a mental operation the learner cannot or would not produce alone. Questioning assists by giving the assistor insight into the learner's developing understanding.
> 6. *Cognitive structuring:* The provision of explanatory or belief structures that organize information and ideas and justify ways of thinking. Cognitive structuring can make an expert's mental schema transparent to a learner.
> 7. *Task structuring:* The chunking, segregating, sequencing, or otherwise structuring of a task into or from components. Task structuring assists learners by modifying the task itself such that elements of a task fit into the learner's ZPD when the entire, unstructured task is beyond that zone. (Tharp, 1993, pp. 272-273)

We bear these forms of teaching in mind as we characterize the acts of teachers and scientists as they guide students during experimentation. We also identify acts that are emphasized by teachers versus scientists. We chose not to include contingency management in our analysis because we did not feel that we had sufficient knowledge, as researchers, of teachers' grading practices or other strategies for meting rewards or punishments.

Methodology

We employed a qualitative approach to study in-depth the ways in which teachers and scientists offered assistance to students during experimentation. Purposeful and convenience sampling was used to identify geographically practical research sites (Patton, 1990) to ensure that teachers' and scientists' acts, primarily their talk, could be observed throughout the process. Data sources included video recordings of classroom activities, interviews of teachers and scientists, and samples of student work (Denzin & Lincoln, 1994; Merriam, 1998). Although we primarily report the results of video analysis here, interview data helped us to understand teachers' and scientists' intentions behind their actions, and review of student work clarified the focus of particular teacher and scientist acts observed in the videos.

Participants

Data were collected from three classes of two teachers in two high schools in the mid-Atlantic region of the United States. For clarity, we chose pseudonyms that start with the letter "S" to denote scientists (Susan and Sandy) and with the letter "T" to denote teachers (Trisha and Ted). Trisha's class was a first-year biology class in a specialty public school with a curricular emphasis on science, technology, and mathematics. Students in this school are typically high achieving and are admitted to the school via an application process in their homeschool systems, which include both rural and urban districts. The 16 students enrolled in this class were mostly 11th graders and worked in pairs to design and conduct their PREP experiments. Trisha is a Caucasian female who, at the time of the study, had more than 10 years teaching experience, 2 years experience with the PREP curriculum, certification in biology, and graduate-level research experience in life science.

The other two classes were 9th/10th grade biology classes in a rural public school that enrolled students spanning a broader range of achievement levels. Each class enrolled 24 students who also worked in pairs on their PREP experiments. Their teacher, Ted, is a Caucasian male with more than 10 years teaching experience at the time of the study, 1 year experience with the PREP curriculum, and certification in biology and chemistry.

Two Caucasian female plant scientists, Susan and Sandy, from a major research university were involved in the program, each partnered with one teacher. Both scientists had research programs involving *Arabidopsis thaliana*, the model organism used in *PREP*, and had headed their laboratories for more than a decade each. The scientists provided *Arabidopsis* seeds and engaged in at least one in-class discussion with students about their experiments and additional interaction through a discussion board on the program's website. Each scientist visited their partner classrooms near the end of the experiments to discuss how students designed and conducted their experiments and the meaning of their results. At the time of data collection, both scientists had participated in PREP for 2 years prior to the study, although they had not worked with Trisha and Ted before. Susan worked with Trisha, and Sandy worked with Ted.

PREP does not involve teachers or scientists in formal training on the program, but rather follows best practices in professional development (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007) by embedding guidance on working effectively as partners and mentoring students in research in day-to-day program activities. Specifically, teachers and scientists meet before the start of the school year to plan their collaboration and learn about PREP resources, such as how-to videos and instructional materials (http://prepproject.org/). Planning is designed according to good partnership practices (Alberts, 1993), emphasizing the importance of meeting the needs and interests of both partners. PREP staff visit classrooms to kick off the program with students and teachers and accompany scientist partners to model inquiry teaching behavior for scientists and offer feedback on their interactions with students. Because both scientists had previous experience with *PREP*, and they may be more expert than the average scientist in partnering with teachers and guiding high school students in experimentation.

Program Context

Although PREP is described in more detail elsewhere (Dolan et al., 2008), it is described briefly here to provide context for the study. PREP starts with a dialogue in the classroom, during which project staff explains to students that their assistance is needed in characterizing the functions of genes in the plant, *Arabidopsis*. Students are familiar with the idea that genes help determine characteristics, but usually only visible characteristics such as height or color. Students generate ideas about why a plant with a disabled gene may look completely normal. Students are introduced to the idea that phenotypes may be revealed through the interplay of genes and environment, such that the impact of disabling a gene may be observable only when the plant must respond to changes in its surroundings. Students consider environmental factors that may influence a plant's growth and are challenged to design and conduct their own 8-week long experiments to compare how mutant plants (i.e., plants with a gene disabled) differ from their wild-type counterparts (i.e., no disabled genes) in their response to an environmental change. Students make comparisons between wild-type and mutant plants as well as treated and untreated plants to draw conclusions about the impact of disabling genes on the plants' responses to the treatment (Figure 1). Students share their results and conclusions with their partner scientists, who ask questions about their findings and explain their interpretations of how students' results fit into what is known in the field. Although students participate in a single investigation, it is extended in duration and complex in nature, requiring students to choose an independent variable (i.e., treatment), continually invent dependent variables in parallel to plants' development (mostly related to changing plant morphometry), make observations and keep records of data over extended time periods, process data to generate graphs, compare observations across the variables, make conclusions, and communicate results to peers and experts. Thus, compared with a series of short investigations, PREP investigations offer a more holistic experience with scientific practice.

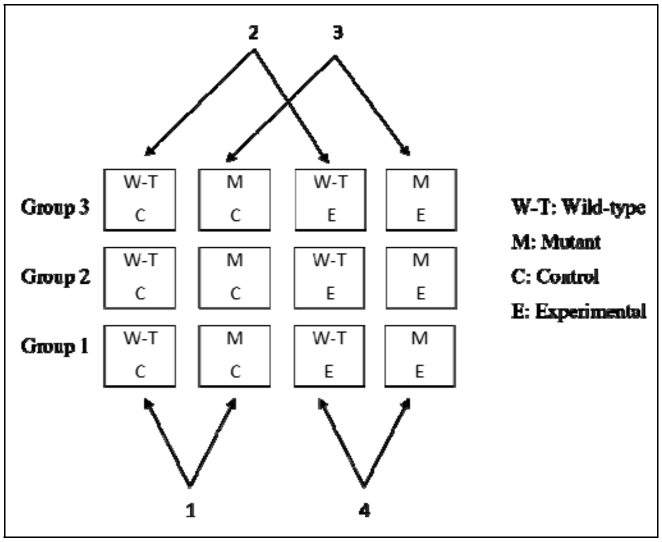

Figure 1. PREP set-up for controlled experimentation.

Note. PREP = Partnership for Research and Education in Plants. Three groups' plants are shown. The numbered arrows indicate the four comparisons students typically make during PREP investigations. Students compare wild-type versus mutant plants in standard laboratory conditions (Comparison 1) to make interpretations about the effect of altering a gene on the plant's growth and development. Students compare control versus experimental wild-type plants (Comparison 2) to make interpretations about the effect of the treatment. Students compare control versus experimental mutant plants (Comparison 3) to make interpretations about the effect of the treatment on genetically altered plants. Finally, students compare wild-type versus mutant plants in experimental conditions (Comparison 4) to identify any changes in the plants' response to the treatment according to their genotypes.

Data Sources and Analysis

Student–teacher and student–scientist interactions were captured through video recordings made by the second author and a graduate assistant. Three video cameras were used to record each class period: one in the backstage to capture the widest possible angle and two on opposing sides of the classroom to capture small group interactions. Four microphones were placed strategically to record as much as possible all discourse in the classroom: one on the front wall to capture whole group discussions and three on student tables to capture small group discussions. The backstage camera connection was switched between the whole class microphone and a student table microphone as needed to record whole group or small group discussion.

The three classes were each recorded five times (15 class sessions total), yielding 45 videos of 45 to 90 min in duration, which were analyzed using the manifest content approach (Erickson, 2006). In this approach, the focus of the analysis is the subject of interest, in our case the verbal actions of teachers and scientists, rather than any latent content. An initial set of codes was developed by the first author, who reviewed all videos, selected two (one per teacher) in which frequent and diverse interactions were observed between students and scientists or teachers, and

Table 1. Teacher and Scientists Acts as Means of Assisting Student Performance.

Means	Specific acts	Teacher	Scientist
Modeling	Showing how to use equipment or software	✓	
	Asking students' plans/preferences for data collection	✓	
	Arranging group meeting style discussions	✓	
	Allowing or encouraging plasticity in variable selection	✓	
	Referencing other groups' data	✓	✓
Task structuring	Methodological structuring	✓	
	Channeling variable selection	✓	
	Channeling variable comparison	✓	✓
	Arranging samples prior to comparisons		✓
Cognitive structuring	Explaining the meaning of the words	✓	
	Explaining why and how to average	✓	
	Diagramming ideas	✓	
	Summarizing ideas discussed	✓	✓
	Providing information or explanation	✓	✓
	Using scientific terminology	✓	✓
	Describing aspects of the nature of science	✓	✓
	Offering methodological suggestions	✓	✓
Questioning	About rationale	✓	✓
	About predictions	✓	✓
	About observations	✓	✓
	About comparisons	✓	✓
	About data/evidence	✓	✓
	About effects	✓	✓
	About inferences	✓	✓
	About conclusions	✓	✓
	About methods or experimental design	✓	✓
	About hypotheses		✓
	About interpretations		✓
Providing feedback	Generic encouragement	✓	✓
	Encouraging for further research/observations	✓	✓
	Providing feedback on students' progress	✓	✓
Instructing	Stating instructional expectations	✓	
	Reminding about timeline and overarching goals	✓	

Note. A check mark indicates that a particular act was performed by the corresponding expert.

used these videos to develop a preliminary code list of teacher and scientist acts. This list was used by the two authors and a graduate assistant to independently code several video segments. The assigned codes were discussed and conflicts were resolved by re-naming, re-defining, dividing, merging, or generating codes. The specific acts that comprise the mature code list are outlined in Table 1.

The coding was done on directly videos. Working independently, the researchers first watched the videos, and then on a word processor coded the video data using the code list. Multiple codes were assigned to the same segment as if multiple actions were taking place concurrently. The lengths of the coded segments varied from as short as few seconds (e.g., confirming) to as long as several minutes (e.g., cognitive structuring). The researchers tabulated (a) the starting and ending time points for each coded segment, (2) the corresponding code(s), and (3) and any notes about the video segment or coding. The researcher used the code list to code one of the three videos of the same classroom period and discussed the codes in 60 to 90 min roundtable meetings. During the meetings, each researcher presented segments that she or he had difficulty in coding, and conflicting points were resolved through discussion. As the researchers watched the videos of same class period captured from different angles, there were overlapping scenes that reinforced code assignments. In addition, the first author checked a random subset of video segments across coders to ensure that the codes were applied consistently. Selected video segments were transcribed verbatim to provide quotes presented here. Transcriptions focused primarily on capturing audio data, but gestures and other details were noted as they were relevant to the coded action. After coding was completed, the "teaching as assisted performance" framework (Tharp, 1993; Tharp & Gallimore, 1988) was used to classify and interpret the codes. Thus, the particular acts of teachers and scientists were derived empirically and then organized and interpreted according to Tharp and Gallimore's framework.

Our analytic approach reveals the range of teacher and scientist acts, patterns in their acts, and trends in the types of acts emphasized by teachers versus scientists. We interpreted the repetition of particular acts as an indicator of the established norms of what an experiment is and how one engages in experimentation. Yet, we chose not to conduct a complete frequency analyses because single acts of experts can direct or shape learners' practice in equally important ways as repetitive acts or "habit." Due to variances in the amount of participation time between teachers and scientists, students' achievement levels in different schools, and their teachers' teaching style (noted in the results and discussions), it would be difficult to draw broader conclusions based on frequency data. However, to provide some insight into how code frequency might vary depending on the particular class session, point in the inquiry process, or involvement of the partner scientist, we provide a sample frequency analysis for four video segments.

Results

Here we present the ways in which teachers and scientists acted to assist students' experimentation performance. Specific acts are grouped according to the teaching as assisted performance framework (Table 1).

Modeling

Most of the modeling acts were performed by teachers. The teachers were always present as the students conducted their work and thus were well positioned to model a range of experimentation-related behaviors for students to imitate. One such act was showing students how to use equipment. For instance, Ted explained, "I think it helps to keep the magnifying glasses close to you," which he then modeled by holding a magnifying glass close to his face and bending down to view the students' plants. The teachers also modeled use of computers by requiring their students to use spreadsheet and graphing software. In Ted's classes, students entered their data into a common file in a class computer, while each student group in Trisha's class used their own laptop to record data. Trisha not only modeled that computers and particular software were used in science but also modeled customary ways of representing data in the scientific community. For example, in one class session, she told a student to "put that [the graph] the other way so that [the] independent variable is on the X axis," thereby modeling customary practices for graphing scientific results.

The teachers modeled other behaviors related to scientific practice as well as the social constructivist and dynamic nature of science (NOS). Ted frequently asked his students about their plans for data collection, for example, "Tell me, what are some data we can collect, looking at your plants right now, at this stage of their life? What things can be measured?" We did not categorize these acts as questioning because, unlike other questioning acts, these prompts addressed the whole class and did not require a specific verbalized response from individual students. Rather, these acts appeared to be prompts that teachers used to suggest to students that scientists could contemplate several executable plans to reach a scientific goal, rather than a single protocol or research design.

Another behavior modeled by teachers was plasticity in selection of dependent variables. For example, Ted encouraged his students to consider collecting data on new variables as their plants grew and new plant structures emerged. Students in one of Ted's classes initially chose to collect data on leaf number and rosette diameter (i.e., diameter of the group of leaves at the base of the stem). As their plants started to bolt (i.e., extend stems), Ted encouraged his students to collect data on the height of the bolt and the percentage of plants that had bolted, as those were the two most relevant variables at the time. Collecting data on rosette diameter and number of leaves was temporarily halted, but students had the option to resume collecting data on those variables in future class periods:

> What else do you want to do? Do you want to do the height? I think counting the leaves and rosette diameter we will hold off on today. So, height of the bolts on average, average height. You can measure and get an average for this pot, measure each of the bolts and average for that pot, okay? Does it make sense to everybody? (Ted)

Ted also encouraged his students to collect new data if they observed something unique or different that they thought might be meaningful. For example, Ted pointed out to his students, "These are the things you need to look at, but if you notice anything at any point in time, or you think, 'Wow, we should start measuring this,' you know." Ted's actions modeled a dynamic approach to data collection, which is distinct from the lock-step approach many students adopt once they begin conducting their experiments.

The modeling act that both teachers and scientists employed was referring to the data of other students. This form of modeling implicitly emphasized the social constructivist NOS where results are disseminated within communities and tested against others' views. For example, in the following excerpt, Ted brings the attention of the entire class to a particular group's plants, and asks other students if they have made similar observations:

> Okay, salt people, once you get your wild-type and mutant control, sit them next to each other. Do you notice anything? Is one set bigger than the other? [Ted examining the plants of a group of students in the front row.] This group's wild-type control seems to be a brighter green than its mutant control. Is that the case of anybody else's or not? I don't know if that is the case for anybody else or not, but did you see any color difference between your wild-type control and mutant control?

Both Sandy and Susan frequently referred to other students' data, for example, "Your data is pretty consistent with the rest of the class, what is it telling you?" (Sandy) or "So you are saying there is not much difference, that seems to be recurring theme here" (Susan). Trisha led whole class discussions that resembled the laboratory meetings she experienced when she was in graduate school. In these meetings, students informally discussed their research plans with classmates and got feedback to improve their research designs.

Task Structuring

We observed task structuring acts that were performed solely by teachers or scientists and by both experts. Methodological structuring was unique to teachers and was an act by which they modified the large task of designing and implementing methods by defining certain aspects of experimental design, such as intensity of a treatment or the format of data entries in spreadsheets. Methodological structuring was more common in Ted's teaching. All PREP students are expected to design an independent variable (i.e., treatment) in addition to the provided one (i.e., genotype). Ted simplified this task by asking each class to select their treatment from a pool of possible treatments that affect plant growth and development (e.g., changes in watering or light). Given that his students had minimal experience with lab learning prior to his class and essentially no experience with scientific inquiry, Ted's interest was in reducing the number of possible treatments so that he could better anticipate and address problems related to particular treatments. Regarding intensity of the treatments, Ted again structured the task by requiring all student groups who used salt as a treatment to apply a certain amount of a specified concentration. His focus was on ensuring that students applied a controlled dose so that their plants would survive the treatment and data could be compared across the class. This structuring also helped students to focus on new aspects of experiment design, such as selecting dependent variables. Here, Ted structured one aspect of the process of experimentation by providing direct guidance to students:

> Ted: Salt groups, after you finish (collecting data), salt groups can water using this. (He shows a beaker containing salt solution.) This water only today. Salt groups we are going to use this beaker. That is all you are watering with today.
>
> Student: Are we watering all of them using this?
>
> Ted: No. Whoa, whoa, whoa. Thank you, thank you. This is very important. My golly, we almost screwed this up. Daniel just made an excellent point. Do we use saltwater on controls, or do we use regular water on controls? The experimental pots, you should have one wild-type experimental and you should have one mutant experimental. Those pots alone, you will use this water. (He shows the salt solution in the beaker.) The control pots, mutant control and wild-type control, we use regular water. Everybody understand?

Ted also structured the task of recording data for his students by emphasizing practices that would facilitate data comparison. He led students in a whole group discussion that yielded a class-wide template for recording data, including what data should be recorded and in what order. The template structure made concrete all of the possible comparisons students could make within their experiments. He expected his students to record their data in a notebook and then enter it in a spreadsheet on a common classroom computer.

Another task structuring act that was unique to teachers was channeling variable selection. Channeling refers to reducing

> the degrees of freedom for the task at hand by providing constraints that increase the likelihood of the learner's effective action; recruiting and focusing attention of the learner by marking relevant task features [in what is otherwise a complex stimulus field]. (Pea, 2004, p. 432)

The students in our study were expected to identify several dependent variables to observe and document to characterize the responses of wild-type versus mutant plants to their chosen treatment. Both teachers facilitated open class discussions regarding selection of dependent variables and otherwise provided a great deal of flexibility in allowing students to choose dependent variables. Yet, they also structured the task by channeling students' interest to a more limited number of dependent variables. In the following example, Ted channels students' choices regarding which data to collect:

> Ted: What about measuring the leaf sizes, like the width and the diameter? That is going to get pretty long and tedious, don't you think? I mean, honestly, let's say I have, how many leaves are on your plants?
>
> Student: Seven (leaves each on six plants).
>
> Ted: So that is 42 leaves . . . Do you want to measure every leaf? Forty-two leaves right now, and later on more, and then figure out the average? We can do that, but I am going to go ahead and say, "We are not going to do that because we don't have time to do that." So how else we can measure the size of the leaves? (Ted)

In this example, Ted structured the task of selecting methods for measuring dependent variables and inventing new, more feasible variables related to leaf size to achieve parsimony.

The task structuring that both teachers and scientists employed was channeling students' comparison of variables. Students recorded observations and measurements over a 6-week period, and thus generated several pages of data representing different variables and different points in time or units of measurement (total, average, etc.). When examining the data, scientists and teachers directed student attentions' to certain comparisons, for instance:

> Ted: You all got your data in there (pointing to a paper spreadsheet)?
>
> Student: Yes.
>
> Ted: I want you to compare your mutant control to wild-type control, and then your mutant experimental to wild-type experimental (making different shaped tick marks to indicate which data should be compared).

These channeling acts structured the comparison tasks for students and modeled experts' approach to making comparisons during controlled experimentation.

Scientists alone offered structure in the form of physical arrangements of the plants to facilitate comparison and interpretation. Generally, the scientists first asked students to compare the control groups to make interpretations about how changing the plant's genotype affected its phenotype (Figure 1, Comparison 1). Then they asked students to compare experimental plants so that they could notice any effects of the treatment on wild-type plants (Comparison 2). They then directed students' attention to comparing mutant plants under the two environmental conditions (Comparison 3). Finally, they asked students to compare wild-type experimental versus mutant experimental plants, so that they could interpret how the plant's genotype affected its response to the treatment (Comparison 4).

Sandy in particular used the physical arrangement of the pots. During one class session, one group of students had their pots on a table and Sandy sorted the pots (in order: wild-type control, mutant control, wild-type experimental, mutant experimental; Figure 1), while muttering the independent variables (e.g., "Wild-type control . . . "). When another group put their pots on the table, Sandy sorted them to align with the first group's pots. After Sandy organized the pots, both she and the students took advantage of the organization to make meaningful comparisons. Sandy started by asking, "What did you guys vary? What did you test in this experiment?" One student explained,

> We wanted to see what effect red light would have on our plants. We thought it might make the color change and we saw that these (gesturing to the treatment plants) were lighter than these (gesturing to the control plants).

Sandy asked a clarifying question, gesturing as the student did, "These (the treatment plants) were all treated with red light, and these (gesturing to the control plants) weren't?" The student agreed. Sandy asked, "If you look the two, this row, here I'll move them around, and this row, any other differences?" while she moved the wild-type plants to the middle of the table and the mutant plants off to the periphery. The conversation about the wild-type subset of plants continued and eventually Sandy asked, "What about the mutants?" Sandy pushed the mutant plants back to the middle and used them as props in her explanation, stating,

> This one (pointing to the mutant control) stayed really healthy, but there was only one plant in the pot, so we think that's [more space for the plant to grow rather than the mutation or treatment] what happened to that one.

Cognitive Structuring

The ways that scientists and teachers helped students organize their ideas and learn methods for thinking were categorized as "cognitive structuring" acts. The teachers alone explained the meaning of words (e.g., a lesion is a kind of a damage) and explained the need for averaging values. The teachers generated diagrams on the board to explain relationships among variables in a way that provided students with a structure to follow. For example, Trisha drew line diagrams to show the effect of a treatment (stressor) on plant, while emphasizing the concepts of genotype and phenotype. Ted used diagrams to explain how to average values. He drew an imaginary plant pot having five growing plants with different rosette sizes and guided students to develop consistent strategies to measure rosette size and average values for each pot. Both teachers and scientists summarized ideas after a long discussion, implicitly highlighting the most salient points that had been discussed. For example, after listening to students' ideas about why there are differences in the growth rate of control and experimental plants, Trisha draws students' attention to an important point:

> Trisha: When the plant is bolting, what it is about to do? Does that necessarily mean that it is growing better because it is happier?
>
> Student 1: No, no.
>
> Student 2: It could be stressed out.
>
> Trisha: It could be stressed out, trying to reproduce before it dies out. So the question is, are the mutants handling the heat better, are they stressed out, or are they dying?

Both teachers and scientists offered information and explanations. In the following excerpt, Ted offers an explanation for why plants in a particular pot may be taller:

> Ted: One thing is a crowding issue, right? I mean, if you have six plants in one pot and four plants in one pot, the pot with six plants will be more crowded. And maybe they are competing for things, like what?
>
> Student: Water.
>
> Ted: Water, what else?
>
> Student: Light.
>
> Ted: Light, things like that. So if these plants seem to be a little bit higher, maybe they are competing for things . . .

The scientists and teachers also indicated the scientific equivalents of the common language terms, but in different ways. Teachers typically referred to both common language and scientific language, such as "Do you all know what these little prickly things are called? Trichomes. What can we say about them?" (Ted). Scientists stressed the scientific versions of terms in more implicit ways. When students expressed an idea in daily language, scientists typically segued into using more scientific terminology, for example,

> Sandy: What I am trying to is to look at the number of seed pods and number of open flowers. Maybe we can do this together. Is there any difference in the number of open flowers between this plant and this plant?
>
> Student 1: This has more open flowers.
>
> Sandy: This has more open flowers than this one. Is there any difference between the number and size of the si- (The scientist hesitates in using the technical term "silique" and instead says seedpod.) seedpods between this plant and this plant? Or this pot and this pot?
>
> Students: (Two students discuss their numbers quietly.)
>
> Sandy: Bigger siliques here. Maybe more siliques here (points the other pot). What about the color of leaves?

Sandy used the scientific term "silique" in place of the less technical term "seedpod," without explicitly defining how the terms related.

Both scientists and teachers explained approaches to thinking about the NOS, but in distinct ways. For instance, the teachers emphasized the quantification of the observations for comparability, while the scientists emphasized the reproducibility of results. Both scientists and teachers frequently referred to others' results while helping students interpret their data. The scientists also provided examples from their own experience, such as

> My students often think that they are failing, my graduate students, because they are not going to have a thesis that is going to answer all these questions. They have actually got more questions. And I tell them, "That is good, it is actually what I am looking for. Your final chapter should be all the questions you have raised because of the new knowledge you have." That is actually what is so fun about science . . . (Susan)

Examples like these offered structures for thinking about how science operates.

Both teachers and scientists provided cognitive structure by making methodological suggestions backed by rationales, although the scope of their suggestions differed. The teachers' methodological suggestions focused more on the short-term goal of completing the investigation, whereas the scientists' suggestions focused more on future exploration. For example, groups in Trisha's class took turns presenting their experimental designs to their classmates. One group did not follow her initial methodological suggestion, so she explained her rationale:

> You have color, colored spots you all were interested in looking at in your plants. I suggested that you get a color wheel and match the colors up. You said we will just go back and look at the pictures later. Well, if you just go back and look at the pictures later do you think there is some difference there and there [flipping through slides on presentation]? Yeah, and it is not the true color, but effects like the lighting, the background. All those things affect how your colors show up. So it is important if you are going to take measurements to not necessarily rely on those pictures. (Trisha)

Methodological suggestions of this sort provided students a structure to enhance the robustness of their methods or reinforce particular standards for the comparability of data across groups.

The scientists' methodological suggestions often invoked new schemas for students to use as they thought about their experiments, typically involving additional methods for confirming interpretations or testing new hypotheses. For example, one group of students was interested in observing leaf color as an indicator of plant health. Students compared the color of leaves in the experimental versus control plants by using a color palette in a computer, matching leaf colors with palette colors by eye. Susan suggested an experimental method that pointed out the inherent bias and uncertain reproducibility of the students' approach:

> We could take ten leaves off this plant and ten off of these, grind them all up, we could weigh them first, wet weight or dry weight. Then you can just make an extract in ethanol. The chlorophyll will come out and then you can measure at 660 nm? 670 nm? Then you can say that, at that wavelength, this is the number for my plants for ten leaves, for experimental versus control, treated versus untreated. That would give you hard numbers and would average it over a number of plants. You can do tons of replicates; you could stay busy all summer doing those experiments! [Laugh] That would give you something you could graph and actually not be so subjective as something like the color chart, where your eye is averaging over the whole leaf. So in a way, it is more appealing, but it also a lot more trouble. But it should be reproducible, too.

Questioning

Questioning acts were the most easily discernible because of their unique syntax and straightforward intention. We distinguished "clarifying" from "questioning" acts according to their intended purpose. We characterized questions as clarifying acts if experts sought to increase their own understanding or ensure that discussants were referring to the same thing (e.g., "What did you say?" or "Are you talking about the wild-type or mutant?"). We characterized questions as questioning acts only if they required students to think about and formulate responses that were not immediately available.

Both teachers and scientists employed a range of questioning acts, including asking students about their rationales (e.g., "Why did you choose to do that?"), predictions (e.g., "What do you think will happen when you treat the plants with nickel sulfate?"), observations (e.g., "What did you observe?"), comparisons (e.g., "What differences did you see between mutant and wild type?"), data/evidence (e.g., "What kind of data did you collect to support that conclusion?"), effects (e.g., "What happened when you grew plants in red light?"), inferences (e.g., "Why is it useful to know mutants grow faster?"), conclusions (e.g., "The mutants were more successful in each of these categories, right? So, what can we conclude about that gene?"), and methods or experimental design (e.g., "What source of nickel did you use?"). The scientists employed a distinct pattern of questioning by alternately asking students about how they went about their experiments, what they observed, and how the growth of wild-type versus mutant and control versus experimental plants compared. The following dialogue illustrates this pattern:

	Dialogue	Questioning about
Sandy:	What did you guys vary? What did you guys test in this experiment?	Method
Student:	We wanted to see what effect red light will have on plants basically. It kind of did a color change; these (experimental) grew better than these were (controls).	
Sandy:	So these were treated with red light and these were not?	Clarifying
Student:	Yes.	
Sandy:	So if you look at just the two, this row (wild-type control) and this row (wild-type experimental). So you noticed that these (wild-type experimental) are lighter green?	Observation
	Any other differences?	Comparison
Student:	We did notice that these kind of did a little better than those did.	
Sandy:	And how did you measure that?	Method
Student:	Well, stalks.	
Sandy:	The bolts?	Clarifying
Student:	Yeah.	
Sandy:	Alright, so what about the mutants? Did you notice anything about the mutants?	Observations

As students discussed their comparisons, scientists then alternated between asking students to describe the differences they observed and the evidence that supported their claims, for instance,

> Susan: If you just compare your mutant to itself, then how did the experimental compare with the untreated plants?
>
> Student: It has like more fruit per bolt, like, in looking at them. This one, the control, looks healthier.
>
> Susan: So how might you quantify that? You are seeing by eye. How could you put numbers on that?
>
> Student: We were using the color chart . . . (The student continues to explain.)

Scientists typically ended their questioning patterns by asking students about their conclusions, for example, "What can we say about this gene? The mutant is missing a gene and it is bigger?" (Sandy). Scientists also asked questions that sought different kinds of information than the teachers did. For example, scientists alone asked students about their hypotheses (e.g., "Could you connect flavonoids to this stress somehow?") and interpretations (e.g., "Okay, mutants grew faster, what does that show you?").

Providing Feedback

Both teachers and scientists provided evaluative feedback to students by comparing their actual performance with a standard. Both gave similar, generic feedback such as "excellent work" or "very nice, guys"; yet their specific feedback differed in ways consistent with their unique realms of praxis. For example, in talking with students who tested the effects of heavy metals and some other environmental agents, Trisha said, "We may continue this as a class project next year in Ecology." Thus, Trisha indicated that students' work had sufficient value to warrant further investigation by new cohorts of students. The scientists gave feedback related to their own research, such as "I would follow up on that in my lab" (Susan), "Very interesting results, I will have to write that down" (Sandy), and "I still want to do the experiment you guys did, I would want to do them side by side" (Sandy).

Instructing

Only teachers employed instructing acts or calls for action from students. Teachers' instructional expectations were typically expressed as daily goals, sometimes loosely stated and other times more specific, for example, "Get a spreadsheet, and get some kind of data today" (Trisha), or

> One thing we are going to do is water our plants, another thing is, we are going to spend some time collecting data and observing our plants, and we are going to do the first now. Why don't you go and grab your plants and bring to the tables? (Ted)

Both teachers oversaw the project timeline and provided students with instructions as to when to start collecting data or give certain treatments. These instructions helped students construct data sets that spanned the 8 weeks of their experiments.

Sample Frequency Analysis

We provide a sample frequency analysis to demonstrate how the code distributions varied. We present coding for four video segments, one for each teacher's solo instruction and one for each teacher's instruction alongside a scientist. The segments where only teachers appeared as experts were captured at time points where students still work on their experimental designs, and the segments where both teachers and scientists appeared were captured at time points where student investigations were close to the end.

Table 2 demonstrates how expert acts differed in each video sample. In the first segment, Ted focused mostly on "cognitive structuring" of students' experimental design by "questioning" students' methods of data collection and stating instructional expectations. In the second segment, Sandy spent most of her time moving from group to group, eliciting students' interpretations by questioning, while Ted monitored other students' progress. In the third video segment, Trisha focused on students' experimental design and provided explanations. Most of Trisha's explanations were related to concepts of mutation and environmental stress as they relate to students' investigations. In the fourth video segment, Susan engaged in extended dialogues with student groups where she described aspects of NOS, provided information or explanations, and made methodological suggestions for future research. Although Trisha was involved in most of the discussions, Susan took the lead.

As evidenced in different code distributions observed in these four segments, it is difficult to make assertions about which codes were more prevalent for the whole data set. Rather, the nature of expert–novice interactions differed in each case depending on where the students were in their investigations, whether scientists were involved, and also how the teachers prioritize student needs given their instructional context. For instance, students in Ted's classes generally needed more cognitive and task structuring than Trisha's students, and Trisha's students needed more guidance in the form of methodological suggestions and more elaborated information through "providing information or explanation."

Discussion and Conclusion

Teacher Assistance

In this study, the teachers acted in a number of ways that were informed by and consistent with their extensive experience with students. First, teachers' instructional acts helped students set daily goals throughout the process of experimentation to ensure that the data were collected and treatments were applied in a timely and systematic way. Second, the teachers offered structures for tasks that they sensed were beyond students' capabilities, such as selecting among the myriad options for treatments or designing new experimental methods. Third, both teachers channeled students' selections of variables because they recognized that their students did not have sufficient expertise to make informed and realistic decisions about what observations to make.

Scientist Assistance

The scientists in this study offered structure to students in making meaningful comparisons by physically arranging students' samples and extensively questioning students about their experimental rationales, observations, comparisons, and conclusions. While both teachers and scientists engaged in channeling acts that helped students to focus on meaningful comparisons of data, the scientists' use of both physical and verbal cues allowed students to visualize the task. The scientists were also uniquely positioned to provide feedback to students about the scientific validity of their experimentation. Cues such as "I would do the same experiment in my lab," were strong indicators of scientists' inclusion of students in a community of scientific practice. These scientists emulated a scaled-down version of their lab discussions by questioning students without requiring them to have deep knowledge of genetics and plant biology.

It is notable that the scientists in this study, both of whom have led research groups focused on experimental biology for over a decade, did not model certain aspects of experimentation for students. This could be the result of timing in that scientists were not in the classrooms at times when modeling experimentation behaviors, such as asking students' plans for data collection, would have been appropriate. Alternatively, the scientists may be more practiced at "teaching by telling" (Mazur, 2009) than the teaching by modeling seen from teachers in this study. Based on this result, programs that involve scientists in K-12 classrooms should consider what scientific behaviors should be modeled for students and schedule scientists' classroom visits accordingly. In addition, such programs should draw scientists' attention to the pedagogical value of modeling and provide concrete examples of how modeling can be operationalized in the classroom.

Commonalities and Distinctions

The teachers and scientists in this study acted to assist students' performance of experimentation, but their actions differed in ways informed by their distinct expertise and authority. For example, both teachers and scientists made use of scientific terminology. Yet, only the teachers explicitly connected scientific and non-technical terms, using both in the same sentence to indicate synonymy or acting to define technical terms using non-technical language. The scientists used technical terms without offering definitions or making explicit reference to less technical synonyms. The scientists appeared unaware of when they were using terminology unfamiliar to students or the teacher. From the situated learning perspective, the use

Table 2. Frequency of Teacher and Scientist Actions in Counts and Percentages in Four Different Segments.

	Segment 1	Segment 2		Segment 3	Segment 4	
Specific Act	Ted only	Ted	Sandy	Trisha only	Trisha	Susan
Modeling						
Showing how to use equipment or software	1 (1.4%)					
Asking students' plans/preferences for data collection	6 (8.5%)			1 (1.6%)		
Arranging group meeting style discussions						
Allowing or encouraging plasticity in variable selection						
Referencing other groups' data	1 (1.4%)			4 (6.5%)		3 (3.9%)
Task structuring						
Methodological structuring	1 (1.4%)					
Channeling variable selection	3 (4.2%)					
Channeling variable comparison	2 (2.8%)		1 (1.9%)			
Arranging samples prior to comparisons						
Cognitive structuring						
Explaining the meaning of words				1 (1.6%)		
Explaining why and how to average	1 (1.4%)					
Diagramming ideas	1 (1.4%)					
Summarizing ideas discussed	4 (5.6%)	2 (13.3%)	1 (1.9%)	3 (4.8%)		3 (3.9%)
Providing information or explanation	5 (7%)	3 (20%)		15 (24.2%)	1 (11.1%)	11 (14.5%)
Using scientific terminology	1 (1.4%)			2 (3.2%)		5 (6.6%)
Describing aspects of the nature of science	1 (1.4%)			1 (1.6%)	1 (11.1%)	14 (18.4%)
Offering methodological suggestions	15 (21.1%)			17 (27.4%)	1 (11.1%)	9 (11.8%)
Questioning						
Questioning about rationale			1 (1.9%)	1 (1.6%)		
Questioning about predictions						1 (1.3%)
Questioning about observations	1 (1.4%)	2 (13.3	5 (9.4%)	4 (6.5%)	1 (11.1%)	
Questioning about comparisons		1 (6.7%)	4 (7.5%)			
Questioning about data/evidence		2 (13.3%)	9 (17%)	3 (4.8%)		3 (3.9%)
Questioning about effects					2 (22.2%)	
Questioning about inferences						6 (7.9%)
Questioning about conclusion		3 (20%)	1 (1.9%)			
Questioning about hypotheses						
Questioning about methods or experimental design	15 (21.1%)		9 (17%)	1 (1.6%)	1 (11.1%)	7 (9.2%)
Questioning about interpretations			21 (39.6%)			1 (1.3%)
Providing feedback						
Generic encouragement			1 (1.9%)			11 (14.5%)
Encouraging for further research or observations	1 (1.4%)					2 (2.6%)
Providing feedback on students' progress						
Instructing						
Stating Instructional expectations	12 (16.9%)	2 (13.3%)		9 (14.5%)	1 (11.1%)	
Reminding about timeline and overarching goals					1 (11.1%)	
Total	71 (100%)	15 (100%)	53 (100%)	62 (100%)	9 (100%)	76 (100%)

Note. As percentages are rounded up, they may not exactly add up to 100 for each column.

of scientific terminology is a contributing element for enculturation process. However, this is valuable only if students can process this new terminology. Therefore, it is critical for teachers to serve as "translators" when scientists introduce new vocabulary or ideas by making connections with existing ideas, encouraging students to ask for definitions, and bringing scientist's attention to these linguistic, cultural, or conceptual barriers (Brown & Ryoo, 2008). Notably, Ted and Trisha took very different approaches to managing classroom activities during visits by the scientists. Ted worked with students who were not engaged in discussion with Sandy, while Trisha participated in discussions between Susan and her students. Thus, Trisha positioned herself to serve as a translator, while Ted may have missed opportunities to do so.

The teachers and scientists in this study both modeled the social constructivist NOS, but again did so in ways that were unique to their distinct professional experiences and goals. The teachers focused on the practical aspects of experimentation that would position students to compare their data across groups, such as measuring and recording data consistently. The scientists focused on the more abstract endpoint of comparison, without much attention to the practical details of getting students there. This difference is reflected in the methodological suggestions made by teachers versus scientists. Teachers made suggestions that related directly to the investigation at hand, and scientists made suggestions about what to do next. Similarly, although both teachers and scientists provided feedback to students regarding the value of their work, each did so in a way that fit their specific contexts and expertise. Trisha indicated that students' research had value to the community of science students because it would serve as a foundation for other students' research. The scientists indicated how students' findings had value to the out-of-school science community because it could or would influence their own research. Similarly, both teachers and scientists offered cognitive structures, but teachers' acts focused on explaining how scientific ideas are connected, while scientists' acts emphasized how to think about the way science is done. Both of their actions indicated that communities of practice were in place. The scientists' feedback implied that students are already functioning as legitimate peripheral participants of the scientific community (Lave & Wenger, 1991; Wenger, McDermott, & Snyder, 2002), and the teachers' comments indicated the presence of an ongoing experimentation-focused learning community in the classrooms.

Both teachers and scientists engaged in frequent questioning, primarily by asking "assisting" questions aimed at "produc(ing) a mental operation that a pupil cannot or will not produce alone" (Tharp & Gallimore, 1988, p. 59). By asking a wide range of questions, teachers and scientists demonstrated the value and practice of questioning in a scientific experiment. We attribute differences in teachers' and scientists' questioning to the unique roles that they assumed in the classroom. Specifically, teachers mentored students on a daily or weekly basis in designing and conducting their experiments, and were more familiar with students' hypotheses and methods. In contrast, the scientists visited with students near the end of their experiments, and their primary aims for the visits were to learn about students' findings and help them make meaning of their data. Thus, scientists asked questions not only to guide students' experimental practice but also to better understand what the students had done.

Another way to look at the scientist and teacher behaviors is from the perspective of expert behavior research (Bransford, Brown, & Cocking, 2000; Chi, 2006). In our study, we saw scientists providing information and explanation about science content and the NOS in ways that were consistent with deep understanding. However, research indicates that much expert knowledge is tacit (Chi, 2006) and experts are not necessarily the good communicators of knowledge to non-experts (Bransford et al., 2000). This problem was solved to some extent by the teachers who were experts in communicating with secondary-level students. Another indicator of scientific expertise is the recognition of patterns and meaningful relationships. Scientist demonstrated how they saw patterns or meaningful relationships and helped students recognize them by channeling variable comparison, arranging samples to draw attention to potentially meaningful relationships, and questioning about patterns. Analyzing problems qualitatively and focusing on problem representation (Chi, 2006) was an expert behavior, particularly evident in Sandy's practice. She asked students to make qualitative comparisons that could not be readily quantified (e.g., comparing plants' health and appearance) and she questioned students about the meaning of their data.

Most of the general expert characteristics noted above apply to expertise in teaching (Berliner, 2001); for instance, having deep knowledge and understanding. However, teacher knowledge is multidimensional including knowledge of content, pedagogy and pedagogical content knowledge (PCK; Verloop, Van Driel, & Meijer, 2001). Thus, the depth of expert teacher knowledge should be understood with respect to those dimensions. The teachers in our study provided information and explanations for students as their scientist partners did. From the pedagogical side, both teachers planned instructional aspects of student experiments, oversaw students' experiments over the 8-week span during which they monitored student progress by questioning. From the PCK side, teachers not only structured the student tasks to manageable units but also provided cognitive structures that supported students' understanding in the specific context of controlled experimentation. In a partnership involving scientists, primary benefit for students can be assumed to gain some level of scientific expertise. However, this does not come from solely by interacting with scientists, but from the whole research experience extended over time that involves various forms of cognitive and task structuring as well as monitoring progress and providing feedback. This makes teaching expertise equally critical and complementary to scientific expertise.

Limitations and Future Research

This study is exploratory in nature and intended to lay a foundation for a larger study of how teacher and scientist acts relate to student outcomes, which was beyond the scope of the current study. Rather, we identified and characterized teachers' and scientists' actions and explored how their distinct backgrounds and expertise might limit or enhance how they assist students' performance of experimentation. We propose that teachers' knowledge of classrooms and students and scientists' knowledge of experimental design and conduct led them to take different actions in the classroom—a sort of yin and yang of scaffolding students in experimentation. The expert actions documented here may be particular to these teachers and scientists or to the process of controlled experimentation. Future research should explore whether experts differ in the assistance they provide to students in other inquiry contexts, such as model building, especially when these contexts are more distantly related to the scientists' ongoing research. In addition, the relationships between expert actions and student outcomes should be studied to determine whether particular actions are more critical for students' development of expertise.

Implications

As grant-making agencies increasingly require scientists to broaden the impact of their research, more are becoming involved in K-12 science education. Our results showed the unique contributions scientists can offer to students during experimentation, such as connecting scientific experimentation in the classroom to the practice of science beyond it. Our results also reveal the shortcomings in both teachers' and scientists' actions that should be mitigated through professional development for scientists and through specifying particular roles for teachers with respect to scientists' actions in the classroom. Indeed, the scientists' actions were complemented by those of the teachers, who acted to transform scientific experimentation in ways that met the logistical constraints of the classroom and the capabilities of their students. When considered more holistically, the teachers and scientists in this study acted in ways that indicated the formation of a community of practice that spanned the domains of science learning and science research (Lave & Wenger, 1991; Wenger et al., 2002). Although it was not the focus of our study, such a community of practice may enable students to cross the border between school science and professional science, and thus "see" themselves as future scientists.

These findings can also inform decision-making regarding "division of labor" in teacher–scientist partnerships. Teachers should be responsible for ensuring that authentic science learning experiences fit the practical constraints of the classroom and are sequenced according to students' capabilities. Likewise, scientists should be tasked with guiding students' practice in ways that model expert behaviors, offer feedback with reference to science practice, and connect authentic practices in the science classroom to the practices of the scientific community. This is consistent with the recent models of scientist–teacher–student partnerships (Falloon, 2012) that suggest teachers should have more active role in determining what is being researched, the goals of partnership should be more openly discussed between teachers and scientists, and activities should be revised as needed to increase the productivity and sustainability of partnerships. It is hoped that increased teacher voice in determining the nature of partnership activities and their implementation will alleviate some of the challenges resulting from scientists' lack of experience working with K-12 students.

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