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Exploring Variability in Science Teachers' Summer Research Experiences: A Cross-Case Comparison of Participation in a Professional Development Program

Abstract

Increasing emphasis on students' understanding of the practices of science and engineering necessitates that teachers themselves possess a strong understanding of these practices. Unfortunately, a teacher's potentially limited engagement in science and engineering practices throughout his or her own education may impede his or her understanding of these disciplines. Numerous professional development programs aimed at providing teachers with authentic science and engineering research experiences currently exist that may help address this gap. This qualitative study sought to describe, in detail, the research experiences of six teachers who participated in a summer Research Experiences for Teachers (RET) in Engineering program. Results indicate that, even within a single program, teachers' research experiences may be highly varied in both content and structure. This draws attention to a need for further consideration of the design of these types of professional development programs to ensure the advancement of participants' understanding of the practices of science and engineering research.

Recent science education reform efforts in the US as described in the *Next Generation Science Standards* ([NGSS]; NGSS Lead States, 2013) and *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (National Research Council [NRC], 2012) emphasize the need for students to become well-versed not only in science and engineering content, but also in the practices of these disciplines throughout their K-12 education. Given that students in K-12 settings may lack opportunities to engage in these practices with professional science and engineering researchers, it is crucial that they are provided with authentic experiences with science and engineering practices in their own classrooms. Accordingly, the *Framework* provides, in part, "a vision for education in the sciences and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields" (NRC, 2012, p.8). Therefore, while it may not be pragmatic for K-12 science teachers to become as knowledgeable about the practices of science and engineering as professionals in these fields, teachers must be well-versed in the practices to be adequately equipped to lead their own students in developing deep understandings of them, as well.

However, for a variety of reasons teachers may not participate directly in the practices of science or engineering during their own education or training, which may impede their ability to mentor their own students effectively. Kindfield and Singer-Gabella (2010) point out that, all too often, teachers at all grade levels "teach science as it was taught to them – giving content-jammed lectures…and running labs that at best include contrived inquiry projects but more often than not follow a cookbook model" (p. 61). Therefore, it is important to consider how to provide teachers with opportunities to learn about the practices of science and engineering that are more authentic, contextualized, and reflective of these fields and, in turn, how their understandings of these practices can then be carried into classrooms in meaningful ways.

Multiple teacher research experience programs have been designed to provide pre- and in-service teachers with exposure to authentic science and engineering research in order to help address gaps in teacher understanding of these disciplines. Overall, descriptions of these programs have revealed that the origins of the projects on which teachers worked typically fell into one of three groups. In some cases, teachers worked with other teachers and/or students under the guidance of a research scientist to complete projects that did not otherwise contribute to ongoing research (e.g., Blanchard, Southerland, & Granger, 2008; Buck, 2003; Hemler & Repine, 2006; Jeanpierre, Oberhauser, & Freeman, 2005; Miranda & Damico, 2013). In other programs, teachers worked with researchers on a project that was part of an ongoing research agenda (e.g., Barnes, Hodge, Parker, & Koroly, 2006; Fraser-Adler & Leonhardt, 1996; Garofalo, Lindgren, & O'Neill, 1992; Gottfried, 1993; Klein, 2009; Klein-Gardner, Johnston, & Benson 2012; Spiegel, Collins, & Gilmer, 1995). Other studies that do not fall into one of these two aforementioned groups indicated that teachers were partnered with research scientists to complete a research project, yet the origins of their research projects remain unclear (e.g., Autenrieth, Lewis, & Butler-Purry, 2017; Dresner &

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Worley, 2006; Haakonsen, Stone, Tomala, & Hageman, 1993), or that there was inconsistency in project origin across participants (e.g., Pop, Dixon, & Grove, 2010).

Although the impacts of these types of programs have been studied in varying degrees, little information has been reported about the specific types of activities in which teachers actually engaged when participating in the programs studied beyond the overall structures and requirements of these programs, especially when teachers worked with researchers on projects part of an ongoing research agenda. Therefore, few conclusions have been drawn about what specific elements of them might be most beneficial for teachers' understanding of science and engineering practices. As Sadler, Burgin, McKinney, and Ponjuan (2010) note, "finer grained analysis of specific programmatic features would yield additional insights that might be leveraged by…designers and managers who conceptualize and run these projects" (p. 253). Consequently, this study highlights the variation that can exist in a single professional development program. Specifically, it describes and compares the research experiences of six high school science and engineering teachers within a Research Experiences for Teachers (RET) summer research program. The study findings underscore the need for collection of these data to inform the development of research experience-based professional development programs so that pre- and in-service teachers will be prepared to lead their students in the pursuit of the practices of science and engineering most effectively.

Theoretical Framework

As noted previously, while teachers may not need to become as knowledgeable about the practices of science and engineering as those who engage in them professionally, some progression toward a more expert understanding of these practices through participation in research may prove beneficial. Given Lave and Wenger's (1991) framework for situated learning through legitimate peripheral participation, it might be expected that participation in the enterprise of science or engineering would provide an individual with a deeper understanding of the practices inherent to these disciplines. Science and engineering research professionals begin as relative "newcomers," learn about the practices of the discipline from more knowledgeable "old-timers" such as research professors and/or graduate students, and eventually transition to acting as "old-timer" participants as they become familiar with the practices, norms, and goals of the field. Therefore, by actually participating in the practices of science and engineering, it is possible that individuals may gain a deeper understanding of these disciplines. A parallel progression could similarly occur for teachers who participate in science or engineering research, allowing them to develop to more expert-like positions with respect to the practices of these fields, which can then be carried back to the classroom. As noted previously, students in K-12 settings rarely have opportunities to work directly with researchers; therefore, science teachers themselves must serve as the relative old-timers in the practices of science and engineering so that they can effectively mentor their students.

Related literature describing learning through intent participation (Rogoff, Paradise, Arauz, Correa-Chavez, & Angelillo, 2003) similarly suggests that individuals may learn through observation of and participation in cultural practices associated with a particular community. With respect to science and engineering research, individuals may gradually become inducted into these communities of practice by progressing from observers to practitioners of science and engineering. For teachers who participate in professional development programs aimed at providing authentic research experiences, they may begin primarily as observers of science and engineering, but ideally they would eventually have opportunities to engage in such research as practitioners. As the authors described:

> [I]n intent participation, learners engage collaboratively with others in the social world. Hence, there is no boundary dividing them into sides. There is also no separation of learning into an isolated assembly phase, with exercises for the immature, out of the context of the intended activity. (p. 182)

Therefore, in keeping with this model, the more-knowledgeable individuals with whom the teachers interact, such as research professors and/or graduate students, are in a position to provide expertise and guidance for the teachers in relation to content and research methodologies throughout their research experience. Meanwhile, these more-expert individuals are also actively engaged in the ongoing research process, "often participating alongside learners—indeed, often learning themselves" (p. 187). These opportunities for drawing upon the knowledge base of others through collaboration around scientific and engineering research may serve as powerful tools for bolstering teachers' understanding of the practices of science and engineering.

Further consideration of teachers' participation in science and engineering research using Goodwin's (1994) lens of professional vision similarly provides insight into the potential benefits of engagement in such activities. Goodwin asserted that professional vision "consists of socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group" (p. 606). Given that science teachers' professional vision is likely centered primarily on teaching, one might assume that their visions are quite unlike that of research scientists and engineers. The distinct professional visions of teacher and scientist or engineer may lead to very different views of the practices of science and engineering, as they likely influence individuals' understanding of these practices. Therefore, it may be argued that, in order for teachers to develop deeper understandings of the practices of science and engineering that more closely resemble that of researchers in these disciplines, they should be exposed to the professional visions of these researchers. This may occur through hands-on participation in research in these fields.

Despite the perspectives provided by Lave and Wenger (1991), Rogoff et al., (2003), and Goodwin (1994), simply working with *any* scientist or engineer in a laboratory or in the field may not necessarily provide an opportunity for the development of understanding of the practices of these disciplines. Lave and Wenger (1991) point out that communities of practice do not simply open information to newcomers. In many instances, these communities may constrain newcomers' opportunities to learn by restricting them from information or chances to participate authentically, which may impede teachers' opportunities to engage in science and engineering as practitioners rather than observers. Therefore, there is a risk that, depending on several factors (e.g., the context of the research, the activities in which the teachers actually engage, the ideology of the researchers with whom they are working), teachers may not be able to become fully immersed in the discipline and/or be exposed to the professional visions of researchers in these fields.

Unfortunately, to date, the extant literature on RET-type programs does not attend to these specific, potential differences in teachers' experiences with science and engineering research. As noted previously, existing studies have described programs in which teachers either (a) worked on projects associated with a researcher's ongoing research agenda (e.g., Barnes, Hodge, Parker, & Koroly, 2006; Fraser-Adler & Leonhardt, 1996; Garofalo, Lindgren, & O'Neill, 1992; Gottfried, 1993; Klein, 2009; Klein-Gardner, Johnston, and Benson 2012; Spiegel, Collins, & Gilmer, 1995); (b) worked on projects that were not directly connected to such an agenda (e.g., Blanchard, Southerland, & Granger, 2008; Buck, 2003; Hemler & Repine, 2006; Jeanpierre, Oberhauser, & Freeman, 2005; Miranda & Damico, 2013); or (c) worked on projects of unspecified or varying origin (e.g., Dresner & Worley, 2006; Haakonsen, Stone, Tomala, & Hageman, 1993). This distinction, in and of itself, may speak to the opportunities presented for teachers to participate authentically in the practices of science and engineering. That is, teachers who work on projects related to an ongoing research agenda may experience fewer constraints on their immersion into the field given that that they are expected to contribute to and advance existing research initiatives.

Of the studies reviewed in which teachers engaged in research projects that were part of an ongoing research agenda, some variation was evident in several overall features of these programs. Length of teacher engagement in research ranged from five weeks (e.g., Spiegel, Collins, & Gilmer, 1995; Klein, 1999) to seven weeks (e.g., Barnes, Hodge, Parker, & Koroly, 2006). Furthermore, some of these programs required that, in addition to the time spent in their respective labs, teachers participate in other activities such as field trips (e.g., to other research facilities/sites) and attend lectures on topics relevant to their research (e.g., Barnes, Hodge, Parker, & Koroly, 2006; Garofalo, Lindgren, & O'Neill, 1992). Participants in some programs were required to present their research to fellow participants and members of the research community involved in the program at the conclusion of their experience (e.g., Fraser-Adler and Leonhardt, 1996; Garofalo, Lindgren, & O'Neill, 1992; Miranda & Damico, 2013). Despite the availability of this general information about differences in the overall structuring and organization of these programs, more detailed recording and analyses of the availability and potential impacts of these and other specific activities in which teachers engage in such professional development programs is needed.

To what extent, then, do research experiences make learning opportunities available for teachers? Alternatively, how might participants be restricted from access to participation and learning? This study investigates the experiences of six teachers who took part in a summer research program in order to detail their individual research activities and tease apart what types of learning opportunities were available to them as program participants as a result.

Methods

The purpose of this qualitative study was to explore opportunities for learning through participation in science and engineering practices made available to participants in a summer teacher research program. This was investigated through a study of six high school science and engineering teachers who were accepted to and participated in a six-week RET in Engineering program for the first time during one iteration of the summer program. Study participants were asked to keep detailed records of their daily activities and the individuals with whom they interacted while engaged in these activities, as well as reflect weekly on their research experiences. The information recorded in the teachers' daily activity logs and weekly written reflections was explored further and verified through interviews with and site visits made by the researcher. The data collected through these measures were examined to determine whether any patterns were evident in aspects of or activities within study participants' research experiences.

Study Context and Participants

Sponsored by the National Science Foundation (NSF), RET programs provide in-service (and, in some cases, pre-service) secondary teachers with opportunities to participate in research and also focus on incorporating these research experiences into classroom instruction. This study focused on participants in a RET in Engineering program for middle and high school science, technology, engineering, and mathematics (STEM) teachers at a private university in the south. Through collaboration with research professors in the university's School of Engineering, teachers participating in this six-week program were expected to complete small-scale research projects that were part of a professor's broader research agenda. With the exception of three-day introductory and concluding periods in the program, RET participants were expected to spend the majority of their time in the program working on their research projects. Although teachers were required to participate in the program along with another STEM teacher from their school, individuals worked separately in different laboratories during their summer research. Participants were matched with research mentors based on their interest in the professor's ongoing research agenda and the extent to which it related to the courses that they taught during the academic year.

STEM teachers were recruited to the RET in Engineering program through program websites and direct contact with schools. These recruitment efforts were focused on teachers in public and private middle and high schools within driving distance of the university, as housing was not provided to participating teachers. All high school science teachers who were selected for the RET in Engineering program for the first time during the year studied were invited to participate in the study described here. First-time participants in the RET program were selected as the focus of this study because it was believed that a lack of prior experience with the program would prevent potential cross-contamination of reported research experiences with previous experiences. Six teachers from four different schools therefore participated in this study. Table 1 highlights the differing research and teaching backgrounds of participants (all participant names and identifiers are pseudonyms).

Although the program in which study participants took part was formally titled Research Experiences for Teachers (RET) in Engineering, and all study participants were placed within engineering-based labs, their experiences with research varied widely. Not only did the departmental affiliations of the labs differ, but even for those teachers who worked in labs within the same department, their specific research focused on dissimilar aspects of a seemingly related topic. Table 2 highlights these differences by providing a summary of the school and departmental affiliations of the labs in which each participant worked, the overall focus of the research in the lab as described by the study participant, and a brief description of each study participant's project while working in the lab. Detailed narrative descriptions of each study participant's research experience follow in the Findings section to facilitate comparison among them.

Data Collection

Once study participants began working on their research projects as part of the RET program, they were asked to complete Daily Activity Logs to document the types and duration of research activities in which they participated throughout the research portion of the RET program, their role(s) in these activities, and the position and role(s) of individuals with whom they interacted in completing these activities. Participants submitted either a paper or electronic copy of their logs to the researcher at the end of each day or week, depending on what format and timing was most convenient. One teacher participant, Mark, asked if it would be acceptable to provide copies of his lab notebook, as it documented his daily activity in detail and because he was experiencing difficulty with computer access during his time in lab. This request was approved with the understanding that documentation of the types of information addressed in the Daily Activity Logs was required. Although this option was also made available to other participants following Mark's request, all other study participants chose to record their information in the activity logs electronically, with most submitting them to the researcher on a daily basis. These logs were thus intended to provide insight into the ways in which the participating teachers engaged in the practices of the labs in which they worked, the types of day-to-day interactions they had with professional researchers, and whether any patterns were evident in these aspects of the teachers' research experiences

Study participants were also asked to complete Weekly Reflections at the conclusion of each week during their research placement. Upon review by the program's director, these reflections were incorporated as part of the program's commitments and were therefore posted on a website maintained by two Research Experiences for Undergraduates program participants (REU's) who worked with the RET program studied. It was through this website that all six study participants independently generated their Weekly Reflections, which consisted of responses to several open-ended questions about what they learned during the week (both in general and about science as a discipline) through the research activities in which they participated. They were also asked to reflect

Table 1. Overview of Study Participants' Educational and Teaching Backgrounds

Teacher Pseudonym	Prior Research Experience	Years of Teaching Prior to RET Participation	Teaching Setting	Courses Taught in School Year Prior to and Year Following RET Participation
Steve	Some prior research with another local university	32	Private K-12 institution	Physics; Pre-engineering
Julia	None	1	Public high school; suburban	Life science; Biology; Anatomy & Physiology
Mark	Some course-based research during Master's program	4	Public high school; suburban	Biology; AP Biology
Robert	None	8	Public high school; suburban	Physics
Alex	Some research as part of Master's program	5	Public high school; suburban	Physical Science
Amy	None	4	Public high school; suburban	Biology; Ecology; Anatomy & Physiology

Table 2. Overview of Study Participants' Research Placements

Participant Pseudonym	Overall Lab Context	Departmental Lab Context	Lab Research Focus	Study Participant's Project Focus
Steve	School of Engineering	Electrical Engineering and Computer Science	Medical image processing for real-time use in surgical procedures	Computer modeling of electric fields in the brain during stimulation by implanted electrodes
Julia	School of Engineering	Biomedical Engineering	Medical imaging for evaluation of human bone strength	Preparation of bone samples for mechanical and imaging testing
Mark	Institute of Imaging Science	Radiology and Radiological Sciences	Medical imaging for evaluation of cancer treatment efficacy	Culturing multiple cancer cell lines; protein analysis of cultured cell lines
Robert	School of Engineering	Mechanical Engineering	Medical applications of mechatronics	Redesign and development of haptic paddle device used in graduate and undergraduate courses
Alex	School of Engineering	Chemical and Biomolecular Engineering	Development of polymer films with water and oil resistant properties	Creation and testing of polymer samples
Amy	School of Engineering	Chemical and Biomolecular Engineering	Design and development of polymer composites as potential substitutes for human bone	Culturing bone cells; preparation and testing of composites using cultured cells

upon whether what they learned would be useful for helping their students understand science as a discipline and, if so, how this might be incorporated into their instruction. Reflection responses were sent to the REU's upon online submission, and those submitted by study participants were forwarded on electronically to the researcher. This measure, along with the Daily Activity Logs, was included to permit examination of the similarities and differences in each participant's individual research experience (e.g., participation in lab meetings, collaboration with other researchers in the lab).

In addition to study participants' completion of Daily Activity Logs and Weekly Reflections, they participated individually in semi-structured Bi-weekly Activity Interviews with the researcher. These interviews were designed primarily as a means to further catalogue participants' daily activities and to provide a check on the accuracy and completeness of the records contained in their Daily Activity Logs and reported in their Weekly Reflections. Study participants were asked to describe the goals of the lab in which they worked, as well as the everyday activity of the lab. Follow-up questions prompted participants to compare their own activity to that of their research mentor and graduate students in the lab, as well as reflect upon what experiences to date had been most helpful in helping them understand science as a discipline. During the weeks that alternated with the Bi-weekly Activity Interviews, the researcher observed participants directly as they worked in their labs during Bi-weekly Laboratory Visits. These visits were intended to provide the researcher with a better understanding of the settings in which study participants worked and their daily activity. These observations were scheduled at the participants' convenience during times that they were conducting work typical of their research experience and during which the researcher was permitted to be present. The Bi-weekly Activity Interviews and Bi-weekly Laboratory Visits were included in this study to directly elicit further information about participants' ongoing research activities rather than rely strictly on written, self-report measures. Taken together, all of these measures were designed to provide the researcher with insight into the extent to which teachers were able to engage in the practices of science and engineering, as well as the means by which the teachers may have been exposed to the professional visions of individuals working in these disciplines.

Although a former teacher participant in the RET in Engineering program, the researcher was in no way affiliated with the program during the time of the study. This study was not designed to be evaluative of the program in any way. Instead, the researcher's prior experience with the RET program fueled an interest in the different ways in which teachers engage with science and engineering research through such forms of professional development. With respect to program recruitment for the iteration studied, all RET participants were selected by the RET program director. The teachers described in this study were selected for focus by the researcher solely based on their courses taught (i.e., science and engineering) and their first-time participation in the RET program.

Data Analysis

All measures described were analyzed qualitatively to compare study participants' summer research experiences; therefore, a set of categories was developed in order to classify and differentiate between individual teacher's research experiences with respect to their engagement in the practices of the field and exposure to the professional visions of scientists and engineers. These categories focused on describing the overall role of each study participant's project in relation to the lab's ongoing research agenda, the study participant's role in their project, the individuals with whom the study participant interacted during these activities and the relative frequency of these interactions, and the study participant's involvement in different types of lab meetings (if any). Using data collected through the various study measures in relation to each of these categories, individual profiles of each study participant's distinct research experience were generated and compared to explore consistencies and variation across these six research experiences.

Findings

As noted previously, narrative descriptions of each study participant's experience are provided below in order to illustrate the wide array of opportunities to engage with science and engineering research provided to teachers through the RET program. Several key distinctions among these research experiences are then compared across participants in relation to how different aspects of a teacher research experience may help make certain practices of science and engineering more or less salient through participation in them, as well as the participants' potential exposure to the professional visions of researchers in these disciplines.

Steve's Research Experience: Medical Applications of Computer Modeling

Steve's project during the RET program was focused on computer modeling of electric fields in the brain for use by neurosurgeons during deep brain stimulation surgery (an intervention for neurological disorders such as Parkinson's disease). Therefore, Steve spent the majority of his time in the lab working on computer programming intended to improve the effectiveness of these models. This took place in a room containing several computers on which Steve and other project personnel worked; however, most of Steve's work was completed independently of the other individuals working in this room. He was allowed a greater degree of autonomy than other teachers participating in this study of research experiences, as he did not have an individual with whom he worked for the entirety of each day of his research experience. Instead, Steve met with his PI and other research faculty multiple times each week in order to talk about his progress, discuss any difficulties that arose for Steve as he completed his programming, and confer about both the practical applications of his work and future directions for his project. He continually expressed the value of these meetings in his Daily Activity Logs, Weekly Reflections, and Bi-Weekly Activity Interviews, and at one point wrote the following:

> Working with [one university researcher] was…awesome - he really takes the time to dig deep… [He] & I worked together on Wed PM & Thurs AM [*sic*]. He also worked on the proof at home and emailed [MATLAB] equations to me. [Steve's PI] also gives his time very freely even though it is crunch time on a big grant. He sees through problems really quickly or in making me explain myself helps me to see a path to solution of a problem. (Steve Weekly Reflection, RET Week #4)

These recurring, one-on-one meetings with those overseeing Steve's work appeared to supplant the need for whole-group research meetings, as no such meetings were held during his time in the lab. Instead, individuals in the lab worked fairly independently but still toward the converging goal of developing the most effective means for compiling and manipulating medical images for use by neurosurgeons during deep brain stimulation surgeries (Steve Bi-Weekly Activity Interviews #1 and #2).

Approximately half way through the RET program, Steve was permitted to view a deep brain stimulation surgery, thereby providing him the opportunity to witness directly the potential impact of his work in a clinical setting. In a Bi-weekly Activity Interview following his observation of the surgery, Steve explained that his experience enabled him to comprehend the existing surgical procedures and how the work he was doing would ultimately help expedite and improve the efficacy of the process. This type of experience was unique to Steve, as no other study participant was presented with opportunities to make such concrete connections to the real-world applications of their work.

Julia's Research Experience: Novel Methods for Evaluating Bone Strength

Most of Julia's research experience took place in a small room used for the cutting and preparation of samples of human bone for mechanical testing and medical imaging. Although the aim of her project was to participate in data collection to assess bone strength through this testing and imaging, the apparatus for cutting the bone was not developed in time for her to do so. Julia worked closely with one graduate student throughout this entire process, observing and eventually assisting with the bone preparation process. The research group of which the graduate student was a part had a centralized room in which they could work, but Julia spent very little time in this space and therefore had little interaction with others who were working on related projects under her mentor PI. Instead, most of her time was spent in the bone-cutting room, which was located in a different part of the building than the main lab space. Despite this, Julia had some opportunities to interact with other researchers throughout her research experience, such as when she spent a portion of a day shadowing a worker in the bone center whom Julia understood to work with both her PI and another PI at the university (Julia Daily Activity Log #10 and Bi-Weekly Activity Interview #3). Contact with her mentor PI primarily consisted of occasions in which he visited the room in which Julia and the graduate student worked in order to monitor their progress on the project. As she explained:

> [Julia's PI] kind of steps in, you know, periodically just to make sure that everything's going okay and to see if we have any questions about what we need to do...then, you know, he'll come back and, or he'll email and say, you know, let's try it this way, or let's do it this way. (0:02:45, Julia Bi-Weekly Activity Interview #3)

She did, however, have some opportunities to work alongside her PI when he filled in for the graduate student with whom she worked, preparing bone samples with Julia when the graduate student had other commitments (Julia Bi-Weekly Activity Interview #2). As with Steve, lab meetings designed to bring together all individuals working on related projects under the mentor PI did not take place during Julia's time in her lab.

In addition to her daily work in the lab, Julia had the opportunity to attend a two-day conference about medical imaging that was held on-site at the university, as well as a seminar conducted within the imaging department. Julia did not actively participate in these meetings, but she was able to listen to presentations made by researchers in the field. Therefore, although she did not attend any sort of lab meeting directly related to her own work, Julia was able to experience settings in which researchers came together to share their work. Unfortunately, the material addressed in these settings, particularly the imaging conference, was beyond the scope of Julia's knowledge. As she stated in one weekly reflection, "I found the conference interesting; however, for the most part I was completely lost" (Julia Weekly Reflection, RET Week #1). This lack of understanding of conference content may have impacted her ability to appreciate its purpose in the same manner of the professional researchers who were in attendance.

Mark's Research Experience: Evaluation of Cancer Treatment Efficacy

Mark's research experience took place in a setting in which several researchers with differing areas of expertise worked within common lab space on individual parts of the lab's larger research goals. These goals focused on using imaging for evaluation of the efficacy of different treatments for cancer. As Mark explained in his final Bi-weekly Activity Interview, some individuals' work focused more on cellular and molecular aspects of the project (e.g., Mark's work with cell culture and protein extraction), while others worked on chemistry-based pieces (although Mark could not clearly explain what this entailed). He worked closely with one graduate student to explore differences in proteins of certain lines of cancer cells and, in so doing, had the opportunity to learn about and ultimately carry out an array of lab techniques.

Despite working in the same physical space as other researchers, Mark described little interaction that took place among them on a daily basis. Mark did have the opportunity, however, to learn about their work while attending weekly lab meetings. During these meetings, led by Mark's PI, each member of the research team reported on their progress on their projects. Mark explained that these meetings "exposed [him to] how the different areas of the lab are working together to achieve the goals in the grant projects currently underway. The chemistry and molecular biology departments require each others [*sic*] expertise to reach new breakthroughs" (Mark Weekly Reflection, RET Week #3). Mark also had the opportunity to present his own work during one of these meetings at the end of his time in the lab. For this experience, Mark used PowerPoint to prepare and present an overview of the work that he and the graduate student completed during his time in the lab. Mark's PI interjected questions and comments intermittently throughout the presentation. Mark responded to the best of his ability, drawing upon the graduate student with whom he worked as needed (Mark Bi-Weekly Lab Visit #2).

Mark had the opportunity to attend the same imaging conference as Julia during his time in the lab. He stated in Bi-Weekly Activity Interview #1, which took place following this experience, that his knowledge base was not great enough to comprehend all that was presented. However, in this interview, he also explained his developing understanding of how imaging can be used in research settings and commented on the fact that individuals working on vastly different types of projects may still rely on the same types of technology to conduct their research. Mark also described the benefit of having been exposed to all of the language and terminology employed by researchers in the imaging field both in Bi-Weekly Activity Interview #1 and Weekly Reflection #1. Therefore, despite his inability to comprehend all that was presented during the conference, Mark was able to glean some understanding of certain aspects of the field and of research as a whole.

Robert's Research Experience: Device Design for Teaching of Dynamics

Robert's project during his research experience was focused on redesigning a haptic paddle device for use in several university courses to help students understand "system dynamics and about… controller interface and force feedback" (0:03:13, Robert Bi-Weekly Activity Interview #2). Although related to the lab's research in mechatronics, Robert's individual project was not designed to help further the overall research goals of the lab in which he worked. Robert worked on this design project fairly independently under the guidance of a graduate student in the lab. He spent most of his time researching existing, comparable devices, developing plans for the redesign of the device, generating computer-based models for the redesign, revising these plans, writing computer code to control the haptic paddle, and sourcing parts for the device. Ultimately Robert aimed to build a prototype of the haptic paddle device before the conclusion of his research experience. During this time, even though the lab occupied a centralized room in which most project personnel worked, Robert typically worked in a separate room and checked in regularly with his cooperating graduate student in order to discuss his progress and potential approaches to his redesign process.

Most of Robert's interactions with his mentor PI took place during weekly lab meetings, which he was able to attend. He described his first experience in this type of meeting as follows:

> I found it informative about the topic and interesting to see how the group interacted to help improve the design of the project. Professors of many years of experience were learning from the research done by the grad student and the grad student was learning from the experience of the professors. It wasn't

> about defending or posturing just pure brainstorming and revisions. (Robert Weekly Reflection, RET Week #1)

Later in his research experience, Robert explained that he felt that another of the weekly lab meetings that he attended had been less helpful, as it seemed less productive and was focused on issues unrelated to his own work (Robert Weekly Reflection, RET Week #4). In addition to these formal lab meetings, Robert also had the opportunity to participate in a brainstorming session focused solely on his own project with his mentor PI and some other lab members. He described this session as being useful for generating ideas as he moved forward with his device design (Robert Bi-Weekly Activity Interview #1). Therefore, although most of his daily interactions occurred mainly with a single graduate student, he did have some opportunities to discuss his project with others, as well as learn about the other projects being pursued in the lab as a whole.

Alex's Research Experience: Development and Testing of Innovative Polymers

Throughout his research experience, Alex's project was focused on testing different types of polymers for their ability to repel both oil and water. This work tied closely to the lab's overall goals of developing polymers that could be used to coat surfaces to make them oil- and water-resistant. Of all study participants, Alex had the most consistent day-to-day activity, as he continuously repeated the same protocol designed to apply the polymers to a surface and test their oil- and water-resistant properties. He completed these procedures independently once he had been trained in the protocol by graduate students working under Alex's mentor PI. At times, in addition to his independent, self-described lab technician-like work of completing the polymer testing protocols, Alex also assisted the graduate students with their projects when it related to Alex's work. This work took place in a lab area that was adjacent to a communal room in which several graduate students worked on their own projects. Therefore, Alex worked in close proximity to these graduate students and interacted with them regularly, both formally about lab-specific issues but also informally during times that they were not working or were waiting to complete next steps in their research protocols (Alex Bi-Weekly Lab Visit #2).

Given that his work took place in cooperation primarily with graduate students, Alex had few interactions with his mentor PI. In his second Bi-Weekly Activity Interview, Alex explained that, instead of regular, whole-group lab meetings, his mentor PI occasionally met with smaller groups of individuals focused on particular aspects of the lab's work. Therefore, Alex had the opportunity to meet with his PI approximately mid-way through his research experience and again toward the end of this time. In these meetings, Alex and the graduate student with whom he worked most closely provided the PI with updates on the progress of their projects and solicited feedback about how to move forward in their work. Beyond this, Alex did not indicate any other occasions during which he encountered his mentor PI in his Daily Activity Logs, Weekly Reflections, or Bi-Weekly Activity Interviews.

Amy's Research Experience: Testing Polymer Composites as Bone Substitute

Amy's work during her research experience was focused on culturing cells and testing how well they grew on different types of polymer composites, which was part of a larger project investigating ways in which human bone could be replaced *in vivo*. She worked closely with one particular graduate student throughout this time, first observing his work and then participating in different aspects of the project alongside him and under his guidance. Amy's Daily Activity Logs reflected a shift in her role more clearly than all other study participants, as she began by describing her role in the day's activities as simply an observer but gradually indicated more hands-on participation over time. For instance, by her third day in the lab, she described her role as "[o]bserver in most of it as well as actually changing out the media and freezing the cells" (Amy Daily Activity Log, Day 3). This then transitioned to descriptions reflecting a more central role, and by the end of her first full week in the lab (Day 7), identified her role as "performer/learner" of the tasks she completed that day. Amy continued to refer to herself in this manner throughout most of the rest of her Daily Activity Logs during her research experience.

The daily environment in which Amy worked was the most consistently populated of the study participants' labs, as she primarily worked in a large laboratory space occupied by several researchers working under her mentor PI. Amy described these individuals as being at different phases in their study of the composites on which they worked (Amy Bi-Weekly Activity Interview #2). Despite this environment, Amy had few direct interactions with individuals other than the graduate student with whom she worked. Additionally, few opportunities arose for Amy to speak with her mentor PI beyond her initial introduction to the lab, as formal lab meetings were not held within this group. Amy did, however, have the opportunity to attend a meeting that drew together the researchers working in her lab and those with whom they collaborated in a bone lab. She explained that "[t]here were a lot of things that the engineering students needed guidance on from the biology students. It made me realize how important it is to colaborate [*sic*] in science" (Amy Weekly Reflection, RET Week #4).

A Closer Look: Similarities and Differences in Participants' Research Experiences

In addition to differences in the labs and projects in which study participants worked as described in the research narratives, notable variation is also evident in the roles of teachers' projects in relation to the lab's overall research goals, teachers' roles in their projects, the individuals with whom the teachers interacted throughout their research, and their involvement in lab meeting experiences. Although this variation surfaced in the research narratives, it is starkly highlighted through side-by-side comparison of the similarities and differences in study participants' research experiences. Table 3 summarizes these aspects of each study participant's research experience and more extended comparisons of these participants' experiences follow.

As can be seen in Table 3, most study participants effectively took on the role of a research assistant while working in their labs, meaning that they worked alongside a researcher, typically a graduate student, assisting them with their work that was selected as the focus for the teachers' summer research. One participant, Alex, also functioned essentially as a technician at times, independently repeating an established protocol to test polymers developed in the lab. Only two study participants (i.e., Steve and Robert) had enough autonomy to develop their own methods for working on their research projects, yet only the work done by Steve was intended to help advance the overall goals of the lab in which he worked. As noted previously, Robert's work was related to his lab's focus on mechatronics, but this redesign was aimed at improving the device for use in a university-level course. Therefore, with respect to the relation of the participant's project to the lab's goals and the study participant's role in working on their project, Steve likely had the most authentic research experience of the study participants. This engagement may have provided him with greater opportunities to gain insight into the practices of science and engineering, as fewer constraints were placed on his participation in the day-to-day research activity within the lab. In contrast, those study participants who experienced less authentic engagement in research practices may have been limited in their ability to develop more expert-like understandings of the disciplines in which they were immersed.

Regardless of study participants' project focus and their role in its completion, all interacted with a range of personnel throughout their research experiences. The relative frequency with which they interacted with these different individuals and the nature of these interactions varied, however. For most study participants (i.e., Julia, Robert, Alex, and Amy), the majority of their interactions were with the graduate students with whom they worked, with some exchanges with the PI heading the lab. Julia and Amy continuously worked alongside a graduate student, while Robert and Alex relied upon the graduate students more as a resource as they continued their work independently. Although both Julia and Robert interacted with their PIs more frequently than Alex and Amy (whose PIs generally checked in on their lab as a whole), these interactions looked quite different. Julia described a few instances in which she worked with the PI doing the same type of work that she did along with a graduate student during his absence. Robert, however, had opportunities to talk through his device redesign

Table 3. Overview of Study Participants' Research Activities

Research Activities	Activity Categories	Study Participant: Steve	Julia	Mark	Robert	Alex	Amy
Overall Role of Project	Part of lab's ongoing research agenda	✓	✓	✓		✓	✓
	Unrelated to lab's ongoing research agenda				✓		
Teacher's Role(s) in Project	Developed own project and methods	✓					
	Developed and followed own methods	✓			✓		
	Independent technician					✓	
	Research assistant		✓	✓		✓	✓
Teacher's Interpersonal Interactions[a]	PI	I	I	I	I	O	O
	Other researchers	C	O	I	O	A/U	O
	Grad student(s)	O	C	C	C	C	C
	Other misc. personnel	O	A/U	I	O	A/U	O
Lab Meeting Experiences	Presented			✓			
	Attended/participated			Weekly	Weekly		
	Attended meeting or event involving broader set of labs and/or researchers	Observed research-related surgery	Attended Imaging Conference; attended seminar	Attended Imaging Conference	Attended multi-lab meeting		Attended multi-lab meeting

[a] Relative frequency of interactions are indicated using the following scale: *C* (consistent; 3 or more times per week); *I* (intermittent; 1-2 times per week); *O* (occasional; less than once per week); *A/U* (absent/unknown; no interactions indicated).

process with the PI and interact with him though their weekly lab meetings. Mark also interacted most frequently with graduate students but also came into intermittent contact with the PI, other researchers, and other lab personnel through his attendance in weekly lab meetings and a conference. He also had the unique opportunity to interact with these individuals as a presenter in one of the group's weekly lab meetings. Of all study participants, Steve interacted most frequently with other researchers during his research experience. Throughout his Daily Activity Logs, Steve emphasized the ways in which he solicited ongoing feedback and advice from other researchers who collaborated with his PI. He also communicated more directly through one-on-one interactions with his PI about his progress on and next steps in his project than any other program participant. It is important to note that Steve interacted most consistently with these individuals (i.e., his PI and other researchers) rather than graduate students, whereas the reverse was true for all other program participants. In this aspect of the research experience (i.e., access to the PI), Steve again appeared to have been subjected to the fewest constraints in his research experience in comparison to the other teachers in the study.

The potential implications of these differences in interpersonal interactions for the development of understanding of the practices of science and engineering are interesting, as one must consider to what extent each participant moved along the trajectory from observer of research practices to participant in them and the potential consequences of such progression. Those who worked closely with graduate students may have had rich opportunities for eventually conducting the same type(s) of work as these graduate students (albeit likely with more supervision) as they progressed from observer to participant, as it is typically the graduate students themselves who are responsible for much of the day-to-day data collection and analysis. Additionally, graduate students may be viewed as less intimidating than a PI; therefore, the teachers who worked closely with them may have felt more comfortable interacting with them, which could foster a more collaborative environment for the teacher.

Despite this, Steve clearly regularly experienced positive, productive interactions with his PI and other research faculty. As noted previously, Steve stated that, "making me explain myself helps me to see a path to solution of a problem" (Steve Weekly Reflection, RET Week #4), which is reflective of his own perceived value of his interactions with his PI. That is, these experiences seem to have made a notable impression on him with respect to his own learning experience in the lab. While this may also have occurred had other teachers been placed in the lab in which Steve worked, he showed a unique level of interest in and enthusiasm for his work, as well as diligence and dedication to his project (as evidenced by his reports of working on it after having left the lab for the day, as well as on weekends), which likely facilitated his ability to interact effectively with his research mentors. Steve's relatively extensive, 32-year teaching experience (in comparison, the next-most experienced teacher had been teaching 8 years at the time of the study) may have facilitated these interactions further, as he not only taught courses most closely linked to the focus of this RET program (i.e., engineering courses), but he also had time and opportunities to participate in professional development programs aimed at advancing his content knowledge (e.g., particle physics) and using university-generated data sets in science curricula. Although these prior experiences did not afford him opportunities to participate in research directly, taken together, they may have contributed to his confidence when interacting with his mentors and bolstered his credibility in the eyes of these mentors.

The varied extent to which study participants engaged in lab meeting experiences is also particularly notable. Participation in such activities may have provided participants with insight into the role and purpose of collaboration in research, as well as provided exposure to the professional visions of a broader set of individuals working on related research. While most of the teachers attended or participated in some type of collaborative meeting or event at some point during their time in their lab, Alex lacked any such experience. Only two study participants, Mark and Robert, regularly attended formal lab meetings. Mark even had the opportunity to present the results of his work during a lab meeting held at the conclusion of his research experience. In following the conventions and routines of the lab as he presented (i.e., presenting data and responding to questions from those in attendance), Mark was provided with the opportunity to step into the role of professional researcher more fully than other study participants during the lab meeting, as he was essentially treated as a full member of the research team during his presentation.

The exposure to the various professional visions held by the individuals with whom study participants interacted throughout their research experiences, both individually and in group settings, may have also impacted their development from more novice to more expert-like understandings of the disciplines in which they worked. That is, study participants who worked primarily with graduate students (e.g., Alex) were exposed largely to the professional visions of those students without experiencing the visions of more senior researchers in the field. In contrast, Steve was exposed was almost exclusively to the professional visions of senior researchers such as his PI. Other teachers, especially Mark, were exposed to a wider range of professional visions. For Mark, such exposure occurred through his interactions with his PI, graduate students, and other researchers in the field (e.g., through lab meetings and the imaging conference that he attended). It is important to consider the potential impacts of such widely varied interpersonal interactions and resulting exposures of the teachers to different professional visions, as the professional visions that they, themselves, ultimately developed may have influenced their understandings of the practices of science and engineering.

Discussion

As these cases illustrate, the lab contexts in which study participants worked, the scope of the projects for which they were responsible, and the specific activities and interpersonal interactions in which they engaged as part of their research experience varied widely across participants. Based on the theoretical underpinnings of this study, these differences all have potential implications with respect to opportunities for learning about the practices of science and engineering. How, then, might Lave and Wenger's (1991) work on situated learning through legitimate peripheral participation, Rogoff et al.'s (2003) focus on learning through intent participation, and Goodwin's (1994) lens of professional vision provide insight into the results of this study? Each of these are discussed below in relation to study participants' research experiences, as well as opportunities for learning about the practices of these disciplines.

Legitimate Peripheral Participation, Intent Participation, and Professional Vision

The perspective of situated learning through legitimate peripheral participation put forth by Lave and Wenger (1991) might suggest that teachers who were more effectively able to progress from newcomers to relatively-experienced old-timers within science and engineering research communities would acquire a deeper understanding of the practices of these disciplines. This, in turn, could enable them to act as the relative old-timers within their own classrooms to help facilitate the development of students' understanding of these practices. Similarly, using the lens of intent participation (Rogoff, et al., 2003), those teachers who were able to progress more from observers to practitioners with respect to research in science and engineering would develop more nuanced understandings of these fields. Considering the potential relevancy of legitimate peripheral participation for professional development in research settings, Robert's project did not directly contribute to the advancement of his lab's broader research agenda. Therefore, he remained more of a peripheral participant in his lab throughout his research experience, even working primarily in a room separate from the rest of the lab. With respect to intent participation, while Robert did, indeed, engage in the re-design of the haptic paddle, he still lacked opportunities to participate in the ongoing research activities of the lab.

In contrast, the other study participants' focus on projects related to their lab's ongoing research agenda may have provided opportunities for them to participate more centrally and act more as practitioners of such research. Such a shift was evident in the ways that Amy described her role in the lab in her Daily Activity Logs. As noted previously, she initially characterized herself as an "observer" of lab activity, but she then transitioned to referring to herself as "performer/learner" of research activity. Additionally, Steve's ability to develop his own project and methods, as well as use these methods to pursue his project, allowed him to engage much like a full-fledged member of his lab. Therefore, some teachers appeared to move along the novice-expert and observer-practitioner trajectories more completely than other study participants.

With respect to Goodwin's (1994) lens of professional vision, all teachers experienced some degree of exposure to the professional visions of practicing scientists and engineers. It is interesting to consider, though, the different types of professional visions they may have encountered through interactions with different types of individuals during their research experiences and the potential impacts of these varied viewpoints. For instance, might participants such as Steve, who primarily interacted with a PI and other established university researchers, have been exposed to different visions of science and engineering when compared with Alex, who experienced only minimal interactions with the PI and mainly worked with graduate students? Perhaps Mark's exposure to the widest range of professional visions during his experience (i.e., his PI, other senior researchers, graduate students, and other miscellaneous personnel) in a variety of settings (e.g., one-on-one interactions, lab meetings, a professional conference) would contribute to the development of a professional vision more in line with that of professional scientists and engineers. This would require insight into the professional visions maintained by all of these individuals with whom the teachers interacted, which was beyond the scope of this study. However, overall one might expect that a professional vision more closely aligned with that of a science or engineering researcher (rather than a K-12 teacher of science or engineering) would reflect more sophisticated understandings of the practices of these disciplines.

Implications for Future Research and Program Design

Given these lenses for consideration of how teachers might become well-versed in the practices of science and engineering, how might we more effectively engage teachers in research experiences that improve their understanding of these disciplines? As noted previously, numerous programs exist that are aimed and providing teachers with authentic research experiences in science and engineering. The results of this study also indicate that, even within a single RET program, the particular experiences that a teacher might have vary widely. Further research is first needed to identify and describe the existing variation in teacher research experience programs at both the programmatic level and at the level of participant's individual experiences within them. It would then be worthwhile considering not only how various programmatic features might provide opportunities for teachers to develop a deeper understanding of the practices of science and engineering, but also how individual's research experiences within these programs might be tailored to highlight crucial aspects of these disciplines. For instance, the differences in the experiences of this study's participants draws attention to the potential importance of relating teachers' individual projects to the overall research goals of the labs in which they work (e.g., Robert's experience compared to the experiences of the other study participants). This relationship may, in and of itself, influence the opportunities for teachers to participate authentically in the practices of science and engineering.

In this way, future iterations of research experience programs can be designed to help advance science teachers' knowledge of the practices of science and engineering so that they, in turn, may be able to more effectively lead and mentor their own students in their developing understandings of these disciplines.

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