Prospective Science Teachers’ Understanding of Science and Engineering Practices

Stacey L. Carpenter, University of California, Santa Barbara
Ashley Iveland, University of California, Santa Barbara
Sungmin Moon, University of California, Santa Barbara
Julie A. Bianchini, University of California, Santa Barbara

Presented at the annual meeting of the National Association for Research in Science Teaching, April 2015, Chicago, IL.

Correspondence concerning this paper should be addressed to Stacey L. Carpenter, University of California, Department of Education, Santa Barbara, CA 93106-9490. Email: scarpenter@education.ucsb.edu

This research was supported by a grant from the National Science Foundation (Grant Number 1240075). However, any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.
Introduction

A Framework for K-12 Science Education [Framework] (National Research Council [NRC], 2012) and the Next Generation Science Standards [NGSS] (NGSS Lead States, 2013) differ from previous science education reform documents (e.g., NRC, 1996) in that they specify eight science and engineering practices rather than emphasize science inquiry processes. This shift away from processes and towards practices stems, in part, from the ambiguity surrounding the term inquiry. The science and engineering practices provide a clearer common language for science educators, and are thought to better describe both the nature of science and the work of science and engineering (Osborne, 2014). According to Bybee (2011) the shift from inquiry to practices “will likely be one of the most significant challenges for the successful implementation of science education standards” (p. 39). With the implementation of these new standards, then, there emerges a need to investigate the ways science teachers, including beginning science teachers, can be effectively prepared to incorporate the science and engineering practices into their instruction.

At the same time, there is a need to investigate how to better recruit undergraduate students majoring in chemistry, physics, and engineering into secondary science teaching. The field in which a teacher holds a postsecondary degree and the amount of postsecondary coursework in that field have been used as indicators of teacher preparation and quality (National Science Board [NSB], 2014). According to the most recent National Survey of Science and Mathematics Education, in 2012, 53% of high school biology/life science teachers had a degree in biology, whereas only 25% of chemistry teachers and 20% of physics teachers had degrees in chemistry and physics, respectively (Banilower et al., 2013; NSB, 2014). At present, only 14% of high school and 7% of middle school science teachers completed one or more engineering
courses in college (Banilower et al., 2013). The training of new physics, chemistry, and engineering teachers -- as well as of future physical scientists and engineers -- is seen as crucial to the economic prosperity of the US, our ability to compete in the global marketplace, and our continued status as a leading knowledge economy (National Research Council, 2010).

The study presented here attempted to address these two needs. It examined a scholarship program at a large public research university in California designed to recruit and better prepare undergraduate chemistry, physics, engineering, and computer science majors for teaching careers in high-need secondary schools. In this program, 12 prospective teachers from these majors had the opportunity to “intern” in local physical science and engineering classrooms. These internships took place in the unique classroom contexts of STEM-focused academies within traditional public high schools -- in classrooms where the prospective teacher participants were able to observe and interact with exceptional mentor teachers and their students.

We focused our investigation on these prospective teachers’ experiences with and understanding of the eight science and engineering practices. The following two research questions guided our study: (1) Which practices did prospective teachers report observing during their placement? (2) What did prospective teachers understand about these practices?

**Conceptual Framework**

Our conceptual framework was grounded both in the eight science and engineering practices and in a situated theory of teacher learning.

**Science and Engineering Practices**

As outlined in the NGSS (NGSS Lead States, 2013) and Framework (NRC, 2012), in order to better understand scientific concepts, students need to engage in the types of inquiry and discourse practices that lead to the development of scientific ideas, and reciprocally, students
need the context of specific content to learn about and develop competence in such practices. Furthermore, engaging in science and engineering practices helps students understand how scientific knowledge is developed, the work of science and engineering, and how science and engineering are related. Learning content in the context of practices makes the content more meaningful and relevant, which increases student interest and motivation (NGSS Lead States, 2013; NRC, 2012). The eight science and engineering practices detailed in the standards are the following: (1) asking questions (for science) and defining problems (for engineering); (2) developing and using models; (3) planning and carrying out investigations; (4) analyzing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations (for science) and designing solutions (for engineering); (7) engaging in argument from evidence; and (8) obtaining, evaluating, and communicating information.

A Situated Theory of Teacher Learning

This research is also framed by a situated perspective on teacher learning. With a situated perspective on learning, the contextual and social aspects of learning are highlighted. Situated learning considers that all learning occurs in a context and that the context and associated activity and tools contribute to what is learned (Brown, Collins, & Duguid, 1989; Greeno, 2006; Putnam & Borko, 2000). Furthermore, using a situated frame, knowledge and learning are understood to be immersed in and developed from social interactions and discourse (Lave & Wenger, 1991; Putnam & Borko, 2000). Learning is conceptualized as increased participation in a community’s practices as well as an individual’s development and use of knowledge as a result of participating in the community (Borko, 2004; Lave & Wenger, 1991; Sawyer, 2006). In short, Borko (2004) defined teacher learning as developing knowledge of teaching through increasing participation in the practices of teaching.
Legitimate peripheral participation describes how teacher learners increase their participation in a community of practice over time (Lave & Wenger, 1991). Learners initially participate in easier, low-risk, yet authentic, tasks. In addition, learners observe more expert members of the community in action and become familiar with the discourse and logic of the community. In this study, the classroom internships were distinct social learning environments where the prospective teachers interacted with K-12 students and teachers, observed teaching and student learning, and participated in authentic classroom practices. We considered the prospective teachers as participating peripherally, yet legitimately, in teaching practice, because they took an instructional role, but did not have full instructional responsibility. For example, prospective teachers helped students during small group activities and individual classwork as well as helped teachers with routine classroom tasks (e.g., taking attendance). Placing prospective teachers with reform-minded teachers was an important part of the program since prospective teachers could observe how experts implemented reform-based teaching strategies. In other words, the prospective teachers were placed within a context of reform-based science instruction where they could observe and participate in science and engineering practices.

**Study Design and Methods**

As prospective teacher participants participated in reform-minded classrooms, they had opportunities to observe how expert teachers engaged students in the eight science and engineering practices. The prospective teachers’ perceptions of whether or not they observed students engaging in the eight practices were understood to be influenced by their prior knowledge of the practices and their experiences in the internship classroom context. We hypothesized that the prospective teachers’ experiences in the internship classrooms would have a positive impact on their understanding of the eight science and engineering practices and how
to implement the practices in science instruction. As such, we examined the prospective teachers’ reported opportunities to experience the implementation of the science and engineering practices and their understanding of those practices observed.

**University and School Contexts**

As mentioned above, the context for this study was an internship program created for undergraduate students pursuing degrees in chemistry, physics, engineering, or computer science to explore teaching as a career. In the first year of program implementation, 2013-2014, 12 prospective teachers participated in engineering-related academies in one of two public high schools located in a high-need school district. Prospective teachers completed a five-week intensive experience at the beginning of the year and, if they chose to, continued to regularly participate during the rest of the academic year. Six prospective teachers participated in the Project-Based Engineering Academy (pseudonym) at one local high school, and the other six, in the Green Academy (pseudonym) at another local high school.

**The Project-Based Engineering Academy.** The Project-Based Engineering Academy (PBEA) admits 100 freshmen high school students annually through a comprehensive application and review process. PBEA students take one integrated course each year during their four years of high school; they complete authentic projects to facilitate their learning of Science, Technology, Engineering, Art, and Mathematics (STEAM). PBEA students learn material from physics, visual arts, and engineering in an integrated course collaboratively designed and taught by a team of teachers. Experiences in class revolve around a series of projects that require the integration of content from each of the STEAM components. Students complete their other classes at the adjoining high school. Prospective teachers assisted students as they worked on their projects in four different spaces: physics, art, computer-aided design, and machining.
**The Green Academy.** The Green Academy (GA) offers high school students courses that focus on environmental education, such as Green Engineering and Green Chemistry. GA is similar to PBEA in that it is multidisciplinary and emphasizes hands-on learning. However, GA is a less formal program: There is no application process and courses are open to all of the high school’s students. Three prospective teachers were placed in Green Engineering and an honors physics course; three prospective teachers were placed in Green Chemistry. In Green Engineering, students learn engineering skills and collaborate on various environmental projects. In Green Chemistry, environmental issues (e.g., climate change, oil spills) are incorporated into a traditional chemistry curriculum. Similar to PBEA, prospective teachers at GA assisted with problem-solving, small group work, and hands-on activities.

**Intensive experience.** As stated above, all 12 prospective teachers participated in a five-week intensive experience at either PBEA or GA. That is, because the university started five weeks after the K-12 school year began, prospective teachers participated in regular high school classes for three hours each day, five days a week, for five weeks. Also during their intensive experience, all prospective teachers attended a weekly seminar. Three of these seminars were taught by university lecturers in Education; two, by lead teachers at the academies. In seminars, prospective teachers discussed their experiences in classrooms and received instruction on ways to effectively teach reform-based science and engineering, including an introduction to the eight science and engineering practices from the NGSS (NGSS Lead States, 2013).

**Continued participation.** Due to the success of the intensive experience, project leadership extended opportunities for prospective teachers to participate in PBEA or GA for up to five hours per week during the rest of the academic year. During the fall quarter of 2013,
eight prospective teachers continued to participate. During winter and spring 2014, five
prospective teachers continued their participation in classrooms.

**Prospective Teacher Participants**

Initially, all 12 prospective teachers in the program participated in this study. However,
two prospective teachers graduated and left the university before the end of the academic year;
thus, they did not participate in the second round of interviews. As such, only data from the
remaining 10 prospective teachers were included in this study. Demographic data about these 10
prospective teachers are shown in Table 1. Six prospective teachers were engineering majors
and completed their internships at PBEA. The remaining four prospective teachers were
chemistry majors and completed their internships at GA: Two interned in Green Chemistry
courses and two interned in physics and Green Engineering courses.

Table 1

*Prospective Teachers’ Demographic Information*

<table>
<thead>
<tr>
<th>Prospective Teacher</th>
<th>Undergraduate Major</th>
<th>Gender</th>
<th>Ethnicity</th>
<th>Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andrew</td>
<td>Mechanical Engineering</td>
<td>Male</td>
<td>Mexican</td>
<td>PBEA</td>
</tr>
<tr>
<td>Ashley</td>
<td>Chemistry</td>
<td>Female</td>
<td>Mexican American</td>
<td>GA</td>
</tr>
<tr>
<td>Brie</td>
<td>Chemistry</td>
<td>Female</td>
<td>Mexican</td>
<td>GA</td>
</tr>
<tr>
<td>Ernie</td>
<td>Mechanical Engineering</td>
<td>Male</td>
<td>Hispanic</td>
<td>PBEA</td>
</tr>
<tr>
<td>Mark</td>
<td>Chemical Engineering</td>
<td>Male</td>
<td>Latino</td>
<td>PBEA</td>
</tr>
<tr>
<td>Mickey</td>
<td>Mechanical Engineering</td>
<td>Male</td>
<td>Japanese American</td>
<td>PBEA</td>
</tr>
<tr>
<td>Nolan</td>
<td>Chemistry</td>
<td>Male</td>
<td>Caucasian</td>
<td>GA</td>
</tr>
<tr>
<td>Paul</td>
<td>Electrical Engineering</td>
<td>Male</td>
<td>Southeast Asian</td>
<td>PBEA</td>
</tr>
<tr>
<td>Reese</td>
<td>Chemistry</td>
<td>Male</td>
<td>Caucasian</td>
<td>GA</td>
</tr>
<tr>
<td>Sally</td>
<td>Mechanical Engineering</td>
<td>Female</td>
<td>Mexican American</td>
<td>PBEA</td>
</tr>
</tbody>
</table>

*Note.* Prospective teachers’ ethnicity was self-reported.
Data Collection

To answer our research questions posed above, we conducted and audio-recorded individual interviews with the prospective teachers. (Demographic information about the prospective teachers was obtained via survey.) More specifically, at the end of the five-week intensive experience, each prospective teacher was interviewed individually. The 10 prospective teachers who remained at the university were again interviewed at the end of the academic year. Interviews lasted on average 45 minutes.

Two researchers (one graduate student and one project evaluator) conducted the interviews using a semi-structured interview protocol. A semi-structured interview protocol was used so that the questions were consistent among prospective teachers but flexible enough to adapt to each prospective teacher as each interview progressed (Brenner, 2006). During the interviews, prospective teachers were presented with cards, with each practice written on a card. The cards were used as a prompt for prospective teachers to discuss the practices. They were asked to identify the practices they had seen during their placement and to provide examples of each practice observed. As this study was part of a larger research project, other questions besides those related to the practices were included in the interviews. For this study, however, we only examined those parts of the interviews related to the practices.

Data Analysis

We began our analytic process by transcribing those parts of the prospective teachers’ interviews pertaining to the practices. We then used a two-tiered coding scheme to analyze the transcripts; we used NVivo 10 software for all coding. For Tier 1 of the coding scheme, we used the eight practices as a priori codes to determine the number and frequency of practices discussed (i.e., to answer research question 1). As we coded for practices, we also coded for
context. That is, we coded whether the participant discussed the practice as connected to the internship placement or as not connected to the placement (e.g., related to the participant’s own high school or university experience). In addition, we coded for negative instances of a practice – when a prospective teacher mentioned that he or she did not observe a practice during the placement. We determined which practices the prospective teachers observed during their placements by counting the practices connected to the placement and subtracting any negative instances.

We then used the Tier 1 codes to organize the data for Tier 2 coding. The goal of Tier 2 coding was to determine what the prospective teachers understood about each practice. We first narrowed our focus to the three practices most frequently discussed by the prospective teachers (based on overall frequency counts). Then, as a way to determine the depth and breadth of their understanding of each practice, we developed codes based on the Practices Matrix from the NGSS, Appendix F (NGSS Lead States, 2013). For each practice, the Practices Matrix indicates the “components of the practice that students are expected to master at the end of each grade band” (p. 50). The Framework refers to these components as competencies (NRC, 2012). We used the competencies under the 9-12 grade band since the prospective teachers were only in 9-12 classrooms. Because we wanted to know which aspects of the practices the prospective teachers were attending to in their discussions, the competencies listed in the Practices Matrix seemed appropriate as criteria for coding. As an example, the competencies for the practice of obtaining, evaluating, and communicating information and our associated codes are shown in Table 2.
Table 2

**Competencies and Associated Codes for Obtaining, Evaluating, and Communicating Information**

<table>
<thead>
<tr>
<th>Code</th>
<th>Competency (as described in NGSS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critically read</td>
<td>Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms</td>
</tr>
<tr>
<td>Compare, integrate, evaluate</td>
<td>Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem</td>
</tr>
<tr>
<td>Gather, read, evaluate info from multiple sources</td>
<td>Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source</td>
</tr>
<tr>
<td>Evaluate validity &amp; reliability; synthesize claims</td>
<td>Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible</td>
</tr>
<tr>
<td>Communicate information in multiple formats</td>
<td>Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically)</td>
</tr>
</tbody>
</table>

Additionally, for each practice, we included “other” and “unclear” codes in the coding scheme. The “other” code was applied if a prospective teacher referred to the practice in a way that was not included in the Practices Matrix. For example, we applied the “other” code when a prospective teacher discussed asking questions and defining problems as the students asking the teacher clarifying questions (rather than scientific questions). We applied the “unclear” code if it was not clear how the prospective teacher was referring to the practice.

**Findings**

**Which Practices Did Prospective Teachers Report Observing During Their Placement?**
As shown in Figure 1, as a collective, the prospective teachers reported observing all eight science and engineering practices during their internship placements. 10 out of 10 prospective teachers reported observing three of these practices; 9 out of 10 prospective teachers reported observing the remaining five practices. Collectively, all practices were observed at both academies.

Figure 2 shows the total number of times each practice was discussed by the prospective teachers. We selected the three most frequently discussed practices for further analysis (see below for findings for research question 2). These three practices were (1) asking questions (for science) and defining problems (for engineering); (2) developing and using models; and (3) obtaining, evaluating, and communicating information.
What Did Prospective Teachers Understand About the Eight Science and Engineering Practices?

As mentioned above, for each of the three most frequently discussed practices, we used the competencies (NRC, 2012) for each practice identified in the NGSS Practices Matrix as our coding scheme – to identify which components of each practice the prospective teachers discussed (NGSS Lead States, 2013). Tables 3, 4, and 5 show the frequency counts of how many times a competency of a given practice was discussed. Overall, the prospective teachers focused on only two competencies of each practice.

**Asking questions (for science) and defining problems (for engineering).** As reflected in Table 3, the Practices Matrix included five main competencies for the practice of asking questions and defining problems, as well as four subcomponents of the “asking questions”
competency (NGSS Lead States, 2013). We found that prospective teachers primarily discussed two competencies of this practice: (1) ask questions, and (2) define a design problem.

More specifically, one of the two competencies prospective teachers frequently discussed was asking questions. We note that we applied the “asking questions” code if a prospective teacher talked about asking scientific questions in general, as well as when more narrowly addressing one of the four subcomponents. As shown in Table 3, prospective teachers most often talked about asking scientific questions in general with an even distribution across asking questions that arise from observations, asking questions to determine relationships between variables, and asking questions to clarify and refine a model, explanation, or engineering problem. In contrast, the fourth subcomponent of asking questions – asking questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships – was addressed only once.

As one example, Mickey argued that asking questions was the most central of the eight science and engineering practices. He saw the other seven practices as starting from and returning to the need to pose researchable questions.

I think…a lot of other ones [practices] come from and start with this one [asking questions and defining problems]. Everyone in the sciences and engineering, if [a], you are not able to ask good questions, and b, if you are not excited about asking the questions, then it is very difficult to get to a point in an investigation where you have to use data. If you are not able or willing to ask questions, then I don’t see how you can get to a place where you can analyze and communicate information.

Prospective teachers addressed not only the science side, but the engineering side of this practice as well. The second most frequently discussed competency of this practice was defining
a design problem. We identified nine instances of prospective teachers referring to this competency. As one example, Mark explained that students found making a spinning top out of a piece of aluminum more difficult than they initially anticipated. For their first design, “a lot of people made ones that were the same thickness all of the way up.” Because these tops failed to spin, the students then had to define a problem: “What makes a better spinning top?” He elaborated: “They make the one [top] that is the same weight all the way up, and it falls over….Their expectation was not what happened, then you have to ask why to fix it…. [They] define[d] the problem when they acted on it.” As a second example, Andrew described how requiring students to build a kinetic sculpture prompted them to define problems related to the size and structure of the sculpture’s base, or box:

The sophomores are making a box for their kinetic sculpture, so not all of the boxes are the same. Some have a slightly bigger inner wall. So all of the boxes don’t have the same diameters. So they have to go on their own and say, “Is this going to work for mine? Do I have to cut more from my layer?” Asking questions and defining problems, there is a lot of this.

Prospective teachers also frequently discussed asking questions in two ways not addressed in the NGSS (these instances were coded as “other”). Prospective teachers talked about asking questions (1) as students asking teachers questions about concepts or directions, or (2) as a pedagogical technique that mentor teachers or the prospective teachers themselves employed to elicit student thinking or to guide students in problem-solving. As an example of the former, Ashley noted that students often asked their teacher to repeat information: “When I hear them [students] asking questions, it’s asking the teacher to say what she just said. There’s no, ‘Why does this happen when I do such and such?’”
Table 3

*Total Number of Times Prospective Teachers Discussed Each Competency of Asking Questions and Defining Problems*

<table>
<thead>
<tr>
<th>Code</th>
<th>Competencies of Practice (as described in NGSS)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ask questions</td>
<td>Ask questions… that arise from careful observation of phenomenain phenomena, or unexpected results, to clarify and/or seek additional information</td>
<td>16</td>
</tr>
<tr>
<td>arise from careful observation</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>arise from examining models</td>
<td>that arise from examining models or a theory, to clarify and/or seek additional information and relationships</td>
<td>1</td>
</tr>
<tr>
<td>determine relationships</td>
<td>to determine relationships, between independent and dependent variables</td>
<td>4</td>
</tr>
<tr>
<td>clarify &amp; refine</td>
<td>to clarify and refine a model, an explanation, or an engineering problem</td>
<td>4</td>
</tr>
<tr>
<td>Evaluate a question</td>
<td>Evaluate a question to determine if it is testable and relevant</td>
<td>4</td>
</tr>
<tr>
<td>Within scope of school resources</td>
<td>Ask questions that can be investigated within the scope of the school laboratory, research facilities, or field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory</td>
<td>1</td>
</tr>
<tr>
<td>Questions that challenge</td>
<td>Ask and/or evaluate questions that challenge the premise(s) of an argument, the interpretation of a data set, or the suitability of a design</td>
<td>5</td>
</tr>
<tr>
<td>Define a design problem</td>
<td>Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations</td>
<td>9</td>
</tr>
</tbody>
</table>

*Note.* Competencies taken from the Practices Matrix (NGSS Lead States, 2013, Appendix F). The frequency for the asking questions code includes total of subcodes and code applied in general.

**Developing and using models.** A second practice often discussed was developing and using models. As with the practice of asking questions above, prospective teachers primarily described two competencies of this practice. More specifically, we identified 22 instances where prospective teachers talked about developing models for the manipulation and testing of processes or systems, and 16 instances where prospective teachers talked about developing or...
using models to illustrate or predict relationships (see Table 4). As an example of the former, Nolan emphasized how modeling systems is particularly important in the physical sciences. He said, “In the physical sciences is where you can use models and start to model systems or even model an element of a system.” As an example of the latter competency, Reese described how his mentor teacher required her physics students to draw a diagram before solving word problems to model known variables in order to illustrate relationships between variables: “When we started doing kinematics, a car drives this long for this distance…the first thing she would always say is, ‘Draw a diagram….Make sure you draw a model.’”

Unlike the other seven practices, prospective teachers often expressed their confusion over what this particular practice meant. For example, Brie noted she needed more help in understanding the practice of modeling:

[The practice of] models is a weird one to me….I never know what the model is.

Because some people define it as something tangibly you can actually touch. Some people define it as a chart you see that just lays everything out neatly.

Along similar lines, Mickey asked the interviewer what was meant by modeling: “What do they mean by models?” He then proposed several possible definitions of modeling and provided examples from his placement. Mickey wondered whether “approximation models” was a model type.

[The high school students] use a lot of approximation models, kind of [to] simplify things down. I guess that [in that] sense, they’re using models. You know, you treat certain things as particles, treat certain things as this or this. And I guess in that way it is a model.
Table 4

Total Number of Times Prospective Teachers Discussed Each Competency of Developing and Using Models

<table>
<thead>
<tr>
<th>Code</th>
<th>Competencies of Practice (as described in NGSS)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluate merits &amp; limitations</td>
<td>Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism or system in order to select or revise a model that best fits the evidence or design criteria</td>
<td>2</td>
</tr>
<tr>
<td>Design a test of a model</td>
<td>Design a test of a model to ascertain its reliability</td>
<td>1</td>
</tr>
<tr>
<td>Develop, revise, use a model</td>
<td>Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system</td>
<td>16</td>
</tr>
<tr>
<td>Use multiple types of models</td>
<td>Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations</td>
<td>4</td>
</tr>
<tr>
<td>Develop a complex model for manipulation</td>
<td>Develop a complex model that allows for manipulation and testing of a proposed process or system</td>
<td>22</td>
</tr>
<tr>
<td>Use model to generate data</td>
<td>Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems</td>
<td>9</td>
</tr>
</tbody>
</table>


**Obtaining, evaluating, and communicating information.** The third practice prospective teachers focused on was obtaining, evaluating, and communicating information. For this practice, prospective teachers most often described the competency of communicating information (see Table 5). Prospective teachers emphasized that communicating information is essential for scientists and that communication is an important skill for all students to learn. For example, Ernie emphasized that being able to communicate information is essential to science and engineering: “It is very important to be able to communicate your information.” He noted
that one high school student, in particular, was able to effectively communicate how she
designed and machined a mobile, the main engineering project assigned to sophomores at PBEA.

I had this one girl who was working on her mobile and making a replica of [the painting] *Starry Night*. And so she goes into the process of making the elements, how to make sure that they weigh closely to her estimated weights. She is then able to explain her math and how far she wants everything set. And so you have students like that. And on the other hand, [you have] ones who started it [their mobiles] last summer and have forgot or who don’t really understand it.

A second competency frequently discussed was the importance of comparing, integrating and evaluating sources of information -- presented in different media or formats, as well as in words -- to address a scientific question or solve a problem. Paul, for example, thought the weakest point of the PBEA program was its lack of emphasis on obtaining, communicating, and in particular, evaluating information. He elaborated: “I think it is really important that they [the high school students learn to] do that. Because in the real world, you do a lot of talking, evaluating especially, for engineering.” Sally, in contrast, thought students engaged in comparing, integrating, and evaluating information when conducting physics investigations at the same academy:

In the physics classroom, when they were dealing with energy and conservation of energy and things like that, springs. They were giving lots of tools, like tracks, and frictionless cars, and springs, and stuff. And then they had to look at what was going on and come up with equations that would illustrate what was happening. . . . And so the groups all came together with what they had found. And the different ways they came about different conclusions.
Table 5

*Total Number of Times Prospective Teachers Discussed Each Competency of Obtaining, Evaluating, and Communicating Information*

<table>
<thead>
<tr>
<th>Code</th>
<th>Competencies of Practice (as described in NGSS)</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critically read</td>
<td>Critically read scientific literature adapted for classroom use to determine the central ideas or conclusions and/or to obtain scientific and/or technical information to summarize complex evidence, concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms</td>
<td>2</td>
</tr>
<tr>
<td>Compare, integrate, evaluate</td>
<td>Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem</td>
<td>10</td>
</tr>
<tr>
<td>Gather, read, evaluate info from multiple sources</td>
<td>Gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source</td>
<td>1</td>
</tr>
<tr>
<td>Evaluate validity &amp; reliability; synthesize claims</td>
<td>Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media reports, verifying the data when possible</td>
<td>0</td>
</tr>
<tr>
<td>Communicate information in multiple formats</td>
<td>Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically)</td>
<td>22</td>
</tr>
</tbody>
</table>


**Discussion**

We found that prospective teacher participants reported observing all of the eight practices during their placements; however, they tended to focus on only a small number of competencies of each practice. As detailed above, the prospective teachers most often discussed the three practices of (1) asking questions and defining problems, (2) developing and using models, and (3) obtaining, evaluating, and communicating information. This finding that
prospective teachers focused on some competencies over others is consistent with Carberry and McKenna’s (2014) research on engineering students’ conceptions of models and modeling in engineering. They found that the engineering students in their study focused on certain aspects of modeling in engineering over others. The students thought of models as physical representations necessary for the design process, but did not think of models as mathematical or predictive as well.

In our study, for the practice of asking questions and defining problems, prospective teachers tended to limit their discussion primarily to two competencies. Prospective teachers were able to talk about scientific questions in general. Prospective teachers also discussed the engineering aspect of this practice (defining a design problem), but did not discuss it as often as the “asking questions” part of the practice. Further, they frequently referred to this practice in ways that are not consistent with how the practice is defined in the NGSS (NGSS Lead States, 2013). Prospective teachers seemed to conflate the scientific practice of asking questions with the classroom practices of students asking teachers questions for clarification or help, and of teachers and prospective teachers asking students questions for pedagogical purposes (e.g., the Socratic Method).

Regarding models, the prospective teachers emphasized developing and using models for manipulating or testing and for illustrating or predicting relationships, but they infrequently discussed evaluating and testing the models themselves. The prospective teachers often admitted their lack of understanding of this practice and expressed confusion over what counts as a model. Prospective teachers’ confusion over the construct of models is important to note. It suggests that the many interpretations of models and modeling can be confusing for teachers, and that this may be a particularly difficult practice for teachers to comprehend.
Additionally, prospective teachers clearly focused on the communication aspect of the practice of obtaining, evaluating, and communicating information. They also tended to emphasize oral communication (e.g., giving presentations) over written communication. Furthermore, the prospective teachers focused on comparing, integrating, and evaluating information, but minimally discussed gathering information and reading.

Implications

We identified two primary implications of our study. One implication is tied to the prospective teachers’ observation of all the practices during their placements, but their focus on a few specific competencies of each practice more than others. This finding might have been a result of the prospective teachers only observing students engaged in these specific competencies. Although the prospective teachers indicated that they observed students engaging in all practices during their placements, they might not have seen students engaging in all competencies of the practices. In other words, how students were engaging in the practices in the classrooms might have been limited. Perhaps the competencies of the practices that the prospective teachers emphasized were the competencies of the practices most prevalent in the classrooms during their placements, or the teachers might have focused on certain competencies more than others. The prospective teachers spent limited time in the classrooms so they might not have seen how teachers engaged students in all competencies of the practices. Further research, such as analyzing video records of the prospective teachers in classrooms, could shed light on this.

Alternatively, the prospective teachers might have focused on certain competencies because their understanding of the practices was limited and they did not recognize other competencies of the practices. The competencies that the prospective teachers emphasized
might reflect what they understood about the practices. For example, prospective teachers might not have understood that obtaining and evaluating information are necessary parts of scientific work, but they did understand the importance of communicating information in science. In future research, more specific interview questions, such as asking prospective teachers for a definition of each practice, could provide more insight into their understanding.

This finding might indicate that exposure to classroom implementation of the practices is not enough to develop prospective teachers’ understanding of the practices. This is similar to previous research on teachers’ understanding of the nature of science, which found that explicit instruction along with engagement in inquiry is necessary to improve teachers’ conceptions of the nature of science (Abd-El-Khalick & Lederman, 2000). Similarly, Carberry and McKenna (2014) concluded that explicit learning experiences about models in engineering improved undergraduates’ understanding and use of models more than the implicit notions of models typically included in an undergraduate engineering curriculum. This finding from our study could be used by teacher educators to provide explicit instruction about the practices and to target their instruction to those aspects of the practices that prospective teachers understand the least.

A second implication is tied to the competencies for each practice identified in the NGSS (NGSS Lead States, 2013). We found that what prospective teachers often said about a practice could usually fit into one of the competencies outlined in the Practices Matrix; however, the fit was not always perfect. In other words, what a prospective teacher said about a practice did not necessarily fit the entire description of the competency, but could fit the description reasonably well. For example, one competency of developing and using models is to “develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between
systems or between components of a system” (NGSS Lead States, 2013, p. 53). We found that prospective teachers often talked about developing or using models to illustrate or predict relationships, but they did not necessarily emphasize that the model should be based on evidence or address the notion of systems. On the one hand, the components of the practices outlined in the Practices Matrix may not be an appropriate coding scheme for determining understanding as they may be too specific and nuanced. The components coded most often tended to be those components that were the most general. On the other hand, if teachers are to include all dimensions of a given competency, they will need support not only in understanding the scope and specificity of each practice, but of each competency as well.

Further, some competencies within a given practice appeared to overlap. One example comes from the competencies identified under obtaining, evaluating, and communicating information. There are three competencies that include evaluation of information, two of which are very similar. One evaluation competency is to “compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem” while another one is to “gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and usefulness of each source” (NGSS Lead States, 2013, p. 65). A second example comes from developing and using models. Several competencies specify developing and/or using models in different ways, yet they seem to overlap and are difficult to distinguish. For example, one competency calls for developing, revising, and/or using a model to illustrate and/or predict relationships between systems or components of a system, and another competency calls for developing a complex model that allows for manipulation and testing of a proposed process or system. The manipulation and testing of a system could be the same as
predicting relationships between components of that system. Furthermore, one competency calls for a complex model whereas the other competencies do not, and complexity of a model is not defined. This finding again suggests that prospective through expert teachers might find some competencies difficult to understand and thus to effectively implement. More guidance to teachers on what each competency of each practice actually means -- as well as specific examples -- is most likely needed.

Conclusion

As argued in our introduction, as the new standards are adopted and implemented, research on teachers’ knowledge of science and engineering practices is certainly needed (NRC, 2012). The purpose of this study was to examine prospective physical science teachers’ understanding of the eight science and engineering practices as they participated as prospective teachers in innovative secondary science and engineering classrooms. We found that the innovative classrooms offered opportunities for the prospective teachers to observe secondary students engaging in all eight practices. Using the competencies of the practices identified in the NGSS for grade 9-12 students, we found that the prospective teachers focused on certain competencies over others.

Our study had several limitations. One clear limitation of this study was our small data set. A second limitation was that we interviewed prospective teachers after their 5-week intensive experience in classrooms and at the end of the academic year. However, we did not interview the prospective teachers before their 5-week intensive experience, so we cannot compare the prospective teachers’ understanding of the practices before and after their 5-week experience. Future research, then, would include pre-intensive experience interviews to better understand how the experience shapes what the prospective teachers understand about the
practices. Future research would also include interviewing mentor teachers and observing classroom instruction to better understand the mis/connections between prospective teachers’ understanding of the practices and actual opportunities provided in classrooms to engage in these practices.

Despite these limitations, our findings suggest that prospective teachers may not understand or recognize all competencies of the eight science and engineering practices that K-12 students are expected to master. This has important implications for teacher education. Teachers need to be adequately supported so that they can fully understand the practices as defined in the NGSS -- and so that they can help their students achieve mastery of all components. Understanding which components of the practices prospective teachers understand the most and which they understand the least can help teacher educators better target their instruction and guidance.
References


