Using inquiry strategies to assess high school student perceptions of science and engineering practices

Accepted 30th January 2020

ABSTRACT

Science education has evolved due to the adoption of the Next Generation Science Standards (NGSS). Districts, classroom teachers, and science educators designed curriculum, instruction, and assessments around the National Science Education Standards (NSES) (1996) and its directive of inquiry-based teaching and learning. The shift in focus from inquiry-based pedagogy to the three-dimensional framework of the NGSS has been challenging and sometimes confusing for some science teachers. The definition of inquiry has expanded in the NGSS through the inclusion of eight science and engineering practices. While research indicates that scientific and engineering practices (SEPs) are present when students participate in inquiry lessons, there is little research that determines specifically which science and engineering practices are present in different levels of inquiry-based lessons. The purpose of this study was to determine to what extent inquiry-based lessons can provide access to different science and engineering practices. The results showed that students identified more SEPs in the open inquiry lesson as compared with the structured inquiry and non-inquiry lessons. Furthermore, students consistently identified the practices: Analyzing and Interpreting Data, and Obtaining, Evaluating, and Communicating Information in all levels of inquiry. However, students did not identify the practices of Developing and Using Models, Using Mathematics and Computational Thinking, or Engaging in Arguments from Evidence in any of the levels of inquiry or the non-inquiry lesson.

Key words: Next generation science standards, inquiry, science and engineering practices, student perceptions, high school science teaching.

INTRODUCTION

The Framework for K-12 Science Education and subsequent Next Generation Science Standards (NGSS) was a collaborative effort between the National Research Council (NRC), the National Science Teachers Association (NSTA), and the American Association for the Advancement of Science (AAAS) to reform science education. The NGSS writing process began summer of 2011. The Framework for K-12 Science Education was published (2012), and the NGSS standards were released April 2013. The new standards eventually set the stage for state Boards of Education to reform science education at the local level (NRC, 2013; Sinatra et al., 2015). Currently, 19 states have adopted the NGSS and 21 states have standards based on the framework (Thompson, 2019). The design and implementation of new science standards were important for K-12 science education in order to keep curriculum and instructional practices relevant to the changing needs of the 21st century learner and to meet demands for today's fast-
paced global economy (NRC, 2012; Sinatra et al., 2015)

Due to the increasing workforce demand for S.T.E.M related professions, it is necessary for students to be educated to prepare them for this future. According to Sinatra et al. (2015), there has been a 17% growth in science-related careers, most of which require a bachelor’s degree. Recognizing that not every child will become a scientist, it is important that science teachers help support the development of a scientifically literate populace. Being scientifically literate is not the memorization or knowledge of science facts, but rather the ability to ask questions, think critically, interpret data, and make conclusions based on gathered evidence (NRC, 1996, 2013). These science skills and thinking processes are transferable across disciplines and needed in the workforce. The implementation of the NGSS necessitates a paradigm shift in the way science is taught and learned in K-12 schools across America. The NGSS framework requires a shift in teaching and learning practices that integrates the disciplinary core ideas of science, cross cutting concepts, and the science and engineering practices. Researchers have demonstrated two focus areas for implementing inquiry models in support of implementing the K-12 Science Framework (e.g., Bowman and Govett, 2015; Haag and Megowan, 2015; Patchen and Smithenry, 2013; Sinatra et al., 2015; Tolbert et al., 2014). The first area of research emphasizes connecting inquiry to specific scientific practices. A second area of research highlights how inquiry involves students in these science practices.

**Connecting inquiry and the NGSS SEPs**

While there is not a singular agreed upon definition for scientific inquiry, the professional literature describes a common theme of students engaging in scientific practices. The K-12 Science Framework maintained the NRC definition of scientific inquiry as, “the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 1996, p. 23). There are different levels of inquiry that can be used depending on the learning tasks assigned to students. Banchi and Bell (2008) described the four levels of inquiry; confirmation, structured, guided, and open inquiry (Table 1). Inquiry is an instructional strategy that can meet the needs of all learners when scaffolded appropriately (Banchi and Bell, 2008; Laru et al., 2012; Llewellyn, 2002).

Each inquiry level depends on how much structure and information the teacher provides to the students. Confirmation inquiry requires students receive the inquiry question, the scientific procedures, and solution from the teacher but work through the explanation process on their own. Structured inquiry requires that students receive the question and procedure, but they discover the solution themselves. During guided inquiry, students receive only the question from the teacher and they decide on a procedure and solution. Lastly, in open inquiry, students are not provided any information from the teacher. The students formulate the question, write a procedure and propose solutions (Banchi and Bell, 2008). Teachers can utilize different levels of inquiry-based lessons based on their students’ needs and which scientific practices they want their students to apply.

While the definition of scientific inquiry from the NSES acknowledges and requires that students participate in scientific practices, the NGSS expands on the concept of inquiry. The SEPs describe the practices scientists and engineers engage in to study the natural world and design solutions to problems. The SEPs provide clarity for teachers by outlining eight specific scientific practices that should be taught:

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

The possibilities for teaching using inquiry have been expanded in the NGSS through the inclusion of the eight scientific practices outlined above. One way to engage learners in the SEPs is through using inquiry-based teaching approaches. The research literature supports the integration of SEPs into inquiry-based approaches. First, researchers have found that implementing inquiry-based teaching approached facilitates the implementation of the SEPs. Second, different levels of inquiry have been found to facilitate the use of different scientific practices (Emden and SumFleth, 2016; Patchen and Smithenry, 2013; Stanford et al., 2016; Hale – Hanes, 2015; Lanni, 2014; Laru et al., 2012, McNeill and Pimentel, 2009). Furthermore, while researchers have found that different levels of inquiry may provide access to specific practices, what may be more important is to determine what level of inquiry provides access to the science and engineering practices of the NGSS and which ones.

**Implementing inquiry facilitates the implementation of SEPs**

According to the NSES, scientific inquiry “refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world”
Table 1: The four levels of inquiry and the information given to the student in each one.

<table>
<thead>
<tr>
<th>Inquiry level</th>
<th>Question</th>
<th>Procedure</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Confirmation Inquiry</td>
<td>Students confirm a principle through an activity when the results are known in advance</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2 - Structured Inquiry</td>
<td>Students investigate a teacher presented question through a prescribed procedure</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3 - Guided Inquiry</td>
<td>Students investigate a teacher presented question using student designed/selected procedures</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4 - Open Inquiry</td>
<td>Students investigate questions that are student formulated through student designed/selected procedures</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Banchi and Bell (2008: 27).

(NRC, 1996: 23). When inquiry models are used as an instructional method, students are required to participate in science rather than just memorize facts (Emden and Sumfleth, 2013; Haag and Megowan, 2015; Patchen and Smithenry, 2013; Quellmalz, et al., 2013; Stanford et al., 2016; Tolbert et al., 2014). The SEPs are one component of the three-dimensional framework required in order to successfully implement the NGSS. The scientific and engineering practices provide a specific focus on what it means for students to engage in the process of scientific inquiry (Bartos and Lederman, 2014). In other words, scientific inquiry is characterized by the behaviors listed in the scientific and engineering practices (Sinatra et al., 2015: 5). Therefore, if teachers can successfully implement inquiry models, where students are actively engaged in doing science, then they are, in turn, implementing SEPs.

Teachers can incorporate inquiry models through model instruction approaches (Haag and Megowan, 2015), whole class inquiry (Patchen and Smithenry, 2013), inquiry using computer simulations (Quellmalz et al., 2013), and the S.S.T.E.L.L.A model (Tolbert et al., 2014). Haag and Megowan (2015) conducted a survey of 710 middle school and high school science teachers to determine teacher readiness in implementing the NGSS. The survey identified teachers with experience using the Model Instruction Program felt more comfortable implementing the NGSS SEPs. The Modeling Instruction Program (MIP) is a program that requires that teachers participate in inquiry during training to better help manage the inquiry process with students in their classroom. The results of this study showed that since the MIP is a way for teachers to better learn how to implement modeling in their classroom, teachers with this experience felt more comfortable implementing the science and engineering practices, specifically the second practice of Developing and Using Models. Implementing inquiry specifically by using the MIP can be one way teachers implement inquiry, and therefore the SEPs, in their classroom.

It is not sufficient for the SEPs to simply be present without students actually perceiving their participation in scientific practices as defined by The Framework for the NGSS. Another way to implement scientific practices is through Whole Class Inquiry (WCI). Patchen and Smithenry (2013) proposed implementing inquiry in the form of Whole Class Inquiry (WCI). WCI is a specific inquiry model, which requires students collaborate as a whole class in order to solve a problem assigned by the teacher. WCI can be implemented at any level of inquiry but typically is used with guided or open inquiry lessons.

Quellmalz et al. (2013) found that middle school students, who participated in the inquiry model group, participated in the design of the investigation which mimics practice number eight, Obtaining, Evaluating, and Communicating Information. Therefore, by implementing inquiry models in the form of interactive computer activities, the study showed that students participated in scientific practices, such as those outlined by the NGSS.

Tolbert et al. (2014) described the Secondary Science Teaching for English Language and Literacy Acquisition (S.S.T.E.L.L.A) model, which emphasizes science practices while reinforcing language and literacy. The researchers investigated the implementation of the S.S.T.E.L.L.A model at the high school level and found that it encourages students to engage in the NGSS scientific practices six, seven and eight; Constructing Explanations (for science) and Designing Solutions (for engineering), Engaging in Argument from Evidence; and Obtaining, Evaluating, and Communicating Information.
Table 2: NGSS scientific practices present in each study.

<table>
<thead>
<tr>
<th>Name of Study</th>
<th>Level of Inquiry</th>
<th>Asking questions and defining problems</th>
<th>Developing and using models</th>
<th>Planning and carrying out investigations</th>
<th>Analyzing and interpreting data</th>
<th>Using math and computational thinking</th>
<th>Constructing explanations and designing solutions</th>
<th>Engaging in argument from evidence</th>
<th>Obtaining, evaluating, and communicating information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emden and Sumﬂethe (2016)</td>
<td>Guided</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lanni (2014)</td>
<td>Guided</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laru et al. (2012)</td>
<td>Guided</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Different inquiry levels facilitate different SEPs

Students need to know they are participating in inquiry and SEPs. It is important that the practices are presented at the most effective level of inquiry and that students recognize that they are participating in the practice. It is important for teachers to understand the process of inquiry, and necessary for students to be cognitively aware that they are participating in inquiry and the scientific practices as well. Stanford et al. (2016) showed that teachers’ experience with implementing inquiry affected students’ level of success in implementing the practice of engaging in argument from evidence. Furthermore, not only did the quality of the students’ argument improve, but also the amount of evidence students used and the frequency of argumentation increased.

Hale- Hanes (2015) conducted a survey of 210 high school chemistry students to determine their perception of learning and their content knowledge while they participated in different levels of inquiry; guided inquiry and open inquiry. Two groups of students participated in each type of inquiry; one group did not receive further discussion on the content, while the other group did. The results of the investigation showed that student groups that received assistance in developing their models and understanding in the instruction performed 29% higher in connecting their models to scientific concepts. Hale-Hines concluded, no matter which level of inquiry is used, it is important that teachers provide instructional support to help the students reach the full potential of the content and practices provided in the lesson.

While these two studies show similar SEPs being accessed in guided inquiry lessons, McNeill and Pimentel (2009) concluded that the major NGSS practices implemented during guided inquiry were Engaging in Argument from Evidence and Obtain, Evaluate, and Communicate Information. Findings from this study showed that argumentation discourse did occur more in the classes where inquiry lessons had been implemented. While the SEP of Engaging in Argument from Evidence was present for this guided inquiry lesson, it was not present in the guided inquiry lessons described by Lanni (2014) and Laru et al. (2012). Lanni (2014) found the same SEPs present in the guided inquiry experiment described by Hale - Hanes (2015). Therefore, just because the findings from the study by McNeill showed that guided inquiry provided access to more argumentation discourse, and thus the SEP of Engaging in Argument from Evidence, doesn’t necessarily mean that all guided inquiry lessons will provide access to this specific SEP.

Connecting research across SEP’s

To draw connections between the research on inquiry-based instruction and SEPs, Table 2 compares the type of inquiry with which SEPs were present in each of the studies referenced in the literature review. Upon analysis of Table 2, the research suggests that each type of inquiry provides access to some of the NGSS scientific practices, but the lessons did not all have consistent scientific practices that were addressed. While these are the scientific and engineering practices that are specifically discussed or evaluated in each of the studies, there is no way to be completely sure that more practices were attained by the students but not assessed. For example, while Engaging in Argument from Evidence is present in most of the guided inquiry lessons, there is no way to be sure that that is the only common practice for all guided inquiry lessons. Furthermore, there are so few studies that address the other levels of inquiry that there is not enough information to determine if more scientific practices can be attained through implementing different levels of inquiry. In fact, in a study by Patchen and Smithenry (2013), a similar
conclusion was stated that supports the idea that there are very few studies that show how inquiry influences the attainability of scientific and engineering practices for students.

Research questions

This study used quantitative data to provide insight into how the science and engineering practices of the three-dimensional NGSS framework are represented or perceived by high school students engaged in different levels of inquiry-based science lessons. Upon review of the literature, there was not a clear pattern of whether certain SEPs consistently aligned with specific levels of inquiry. Therefore, the questions this study sought to address were:

1). Do students perceive more SEPs as the level of inquiry increases from non-inquiry through structured inquiry to open inquiry?
2). Which of the eight NGSS scientific practices do students report in a non-inquiry lesson, a structured inquiry lesson, and an open inquiry lesson?

MATERIALS AND METHODS

The data from this study were collected over three years in high school science classrooms. The lesson set of three lessons, which varied in terms of level of inquiry was conducted at the same time each year and the population of students remained similar.

Participants

According to the Illinois Interactive Report Card (2019), the student body of the suburban high school was 74% White, 3% Black, 14% Hispanic, 6% Asian, and 2% two or more races. The student body contained students that were 15% low income, 3% Limited English Proficient (LEP), and 11% with Individualized Education Programs (IEP) (Illinois State Board of Education, 2019)

Data were collected from three sections of the science elective course, Animal Behavior. As an elective, both 11th and 12th grade students were enrolled in the course. Only the data from students who were present for all three lessons in the lesson set were included in the data analysis. For year one, the 2016 - 2017 school year, data was collected from three sections of the Animal Behavior course (n= 85 students) with a final sample size of 30 students. For year two, the 2017-2018 school year, data was collected from three sections of the Animal Behavior course (n= 82 students) and the final sample size was 53 students. Lastly, for year three, the 2018-2019 school year, data were collected from three sections of the Animal Behavior course (n= 61 students) and the final sample size of 17 students.

Data sources and analysis

Multiple primary data sources (Table 3) provided opportunities to learn more about the implementation of the SEPs from the teacher perspective and identification of SEPs from the student perspective. As a participant observer, the first author led students through a training activity where they read descriptions of three lessons and practiced identifying the SEPs. Students then participated in a three lesson set, in the order of non-inquiry, structured inquiry, and open inquiry (Table 4). After each lesson, students completed a lesson survey as a tool to identify how often each practice was present in the lesson in which they participated. After completion of the three lessons, students completed a Lesson Comparison Survey, where students compared all three lessons to each other and selected which lesson had the most practices present overall.

Lesson surveys: Students were administered a survey following each lesson in the lesson set. Survey items asked students to identify the extent by which each SEP was present in the lesson on a four-point rating scale of not at all, very little, some, or very much. Once they selected the level of attainability of each practice, students were asked

<table>
<thead>
<tr>
<th>Table 3: Timeline of data sources.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>During semester</strong></td>
</tr>
<tr>
<td>Before Lesson Set was taught</td>
</tr>
<tr>
<td>After each individual lesson in the Lesson Set was taught</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>After all three lessons in the Lesson Sets were taught</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data sources and analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple primary data sources (Table 3) provided opportunities to learn more about the implementation of the SEPs from the teacher perspective and identification of SEPs from the student perspective. As a participant observer, the first author led students through a training activity where they read descriptions of three lessons and practiced identifying the SEPs. Students then participated in a three lesson set, in the order of non-inquiry, structured inquiry, and open inquiry (Table 4). After each lesson, students completed a lesson survey as a tool to identify how often each practice was present in the lesson in which they participated. After completion of the three lessons, students completed a Lesson Comparison Survey, where students compared all three lessons to each other and selected which lesson had the most practices present overall.</td>
</tr>
</tbody>
</table>

Lesson surveys: Students were administered a survey following each lesson in the lesson set. Survey items asked students to identify the extent by which each SEP was present in the lesson on a four-point rating scale of not at all, very little, some, or very much. Once they selected the level of attainability of each practice, students were asked |
to select a SEP for which they chose "some" or "very much" and to explain how that SEP was present in the lesson.

**Comparison of Lessons Survey:** Students took a final survey after participating in all three lessons in the lesson set. First, students were asked to identify which of the three lessons had each SEP present the most. Students could choose, none of the lessons, the non-inquiry lesson – Reading Strategy, the structured inquiry lesson – Egg Hunt Activity, or the open inquiry lesson – Beetle Lab. The second question required students to answer which of the three lessons in the lesson set had the most practices present overall. Once students chose, they answered an open-ended question to describe why they believed that lesson had the most SEP's present overall.

Both the Lesson Surveys and the Comparison of Lessons Survey appeared in a grid format, which allowed the students to see all the SEPs at once. In this way, students were able to self-consciously compare all the SEPs when they responded which provided a validity check on their responses. Also, both authors identified common themes connected to the two research questions and triangulated the themes across the multiple data sources to confirm the patterns in the data. Triangulation across multiple data sources from the interpretation of multiple authors supports the validity and trustworthiness of the findings presented below.

**RESULTS**

The purpose of this study was to determine if students perceive more SEPs as the level of inquiry increased throughout the lesson set and which of the eight SEPs they perceived in each lesson. Analysis of student data suggested that when students participate in inquiry-based lessons, they perceive more NGSS SEPs than non-inquiry lessons. Furthermore, students consistently identified the practices: Analyzing and Interpreting Data, and Obtaining, Evaluating, and Communicating Information in all levels of inquiry. However, students did not identify the practices of Developing and Using Models, Using Mathematics and Computational Thinking, or Engaging in Arguments from Evidence in any of the levels of inquiry.

**Increased perception of NGSS SEPs based on type of lesson**

The first research question we asked was if students identify more SEPs as the level of inquiry increased from non-inquiry through structured inquiry to open inquiry. The results of the Lesson Survey and Comparison of Lesson Survey were both used to answer this question. To interpret the findings, the results from each student for each of the three Lesson Surveys were compiled into a single data table. Practices selected were only considered valid if the student perceived the practice as "some" or "very much" present. This is because if the students selected the practice as present "not at all" or "very little" it can be concluded that the particular SEP was not identified for that lesson. The sum of all student responses from each Lesson Survey rated as "some" or "very much" was compiled by lesson type. The total number of SEPs selected "some" or "very much" were then averaged (Table 5). To provide a validity check to the data, the Comparison of Lesson Survey results were used (Table 6). In the Comparison of Lessons Survey, students selected the lesson they perceived having the most practices overall, after participating in each of the lessons. The percentage of students who selected each lesson as having the most practices present overall was calculated.

**Students identified more SEPs as the level of inquiry in a lesson increases:** In the first year of this study, students identified on average 3.8 SEPs in a non-inquiry lesson, 4.8 in a structured inquiry lesson, and 4.9 SEPs in an open inquiry lesson. In year two of the study, students identified on average 3.7 SEPs in a non-inquiry lesson, 4.5 in a structured inquiry lesson, and 5.8 in an open inquiry lesson. In year three, students identified on average 4.6 SEPs in a non-inquiry lesson, 4.6 in a structured inquiry lesson, and 6.5 in an open inquiry lesson (Table 5).

According to the students’ responses, the open inquiry lesson - Beetle Lab was consistently identified as having the most SEPs across the three years of the study. In year one,
Table 5: Average number of SEPs identified by student per lesson type by year.

<table>
<thead>
<tr>
<th>Lesson type</th>
<th>n = 30</th>
<th>n = 53</th>
<th>n = 17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
</tr>
<tr>
<td>Non-inquiry</td>
<td>3.8</td>
<td>3.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Structured inquiry</td>
<td>4.8</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Open inquiry</td>
<td>4.9</td>
<td>5.8</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Notes. Average number of SEPs perceived (“some” or “very much”) versus lesson. The highest amount of SEPs possible is 8. The amount of SEPs increases as the level of inquiry increases. The most SEPs are perceived in an open inquiry lesson.

Table 6: Percent of students that identify a lesson as having the most practices overall.

<table>
<thead>
<tr>
<th>Lesson type</th>
<th>n = 30</th>
<th>n = 53</th>
<th>n = 17</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year 1</td>
<td>Year 2</td>
<td>Year 3</td>
</tr>
<tr>
<td>Non-inquiry</td>
<td>0.10</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>Structured inquiry</td>
<td>0.40</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Open inquiry</td>
<td>0.50</td>
<td>0.94</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Notes. Lesson that had the most practices overall. The highest percentage of students identify that the Beetle Lab (Open Inquiry) had the most SEPs overall.

50% of study participants identified the Beetle Lab as having the most SEPs, 94% of students in year two, and 95% percent of students in year three. Overall, when implementing open inquiry teaching styles, students perceive more NGSS SEPs than non-inquiry or structured inquiry lessons.

Students identified more SEPs in the open inquiry lesson. When engaged in an open inquiry method of science instruction, students identified an average of 4.9 SEPs in year one, 5.8 SEPs in year two, and 6.5 SEPs in year three (Table 5). Also, to provide a validity check to the data, the Comparison of Lesson Surveys results were used (Table 6). According to the students’ responses, the open inquiry lesson - Beetle Lab was consistently identified as having the most SEPs overall across the three years of the study. In year one, 50% of study participants identified the Beetle Lab as having the most SEPs, 94% of students in year two, and 95% percent of students in year three. In general, when students were engaged in science lessons taught using open inquiry teaching strategies, students perceived more NGSS SEPs than non-inquiry or structured inquiry lessons.

Frequency of student perception of certain NGSS practices

The second question asked was which of the eight NGSS SEPs do students report in a non-inquiry lesson, a structured inquiry lesson, and an open inquiry lesson? Results from the Lesson Surveys of year three of the study were used to support this finding (Table 7). A practice was considered present if 13 or more participants identified the practice as present in the lesson (n=17). Therefore, if the number was less than 13 the practice was not considered significant.

Findings of the present study showed that while engaged in a non-inquiry based lesson, at least 75% of the students identified three common SEPs: 1) Analyzing and Interpreting Data, 2) Constructing Explanations and Designing Solutions, and 3) Obtaining, Evaluating, and Communicating Information. In the structured inquiry lesson, 75% of students identified two common SEPs from the non-inquiry lesson: 1) Analyzing and Interpreting Data, and 2) Obtaining, Evaluating, and Communicating Information. Students identified 5 SEPs in the open inquiry lesson; 1) Asking Questions and Defining Problems, 2) Planning and Carrying Out Investigations, 3) Analyzing and Interpreting Data, 4) Constructing Explanations and Designing Solutions, and 5) Obtaining, Evaluating, and Communicating Information.

In summary, students identified two practices in all three science lessons: 1) Analyzing and Interpreting Data and 2) Obtaining, Evaluating, and Communicating Information. Students did not identify three scientific practices in any of the lessons: 1) Developing and Using Models, 2) Using Mathematics and Computational Thinking, or 3) Engaging in Arguments from Evidence. The data suggested that these practices were either not fully implemented in the lesson or that, when implemented, students did not readily identify them.

DISCUSSION

For veteran science teachers who were around for the implementation of the National Science Education Standards (1996), inquiry-based teaching and learning was the hallmark of best practice in science teaching. With the advent of the Next Generation Science Standards (2013), science educators, teachers and department chairs needed
to reconceive curriculum and units of instruction around the three-dimensional framework of the NGSS. While the content of the standards remained similar, a major shift in thinking needed to happen around the science and engineering practices. We hypothesized, if teachers can successfully implement inquiry models, where students are actively engaged in doing science, then they are, in turn, implementing the science and engineering practices. Our findings suggest that this may be true for some, but not all of the SEP’s.

Students cannot simply participate in lessons where the NGSS SEP’s are present, but rather they need to be aware that they are engaging in inquiry processes to help them successfully participate in the scientific practices. Meaning making needs to occur for teachers as well as students. Using inquiry-based lessons may be a bridge for teachers as they transit to full implementation of the three dimensions of the Next Generation Science Standards including the science and engineering practices. We wanted to investigate if students perceived more SEPs as the level of inquiry increases from non-inquiry through structured inquiry to open inquiry if so, which SEPs do they perceive. Our findings suggest that students may perceive more practice, but the practices may be similar across lessons or unique to particular lessons.

The results of the present study showed that students perceived the most practices in open inquiry lessons and over the years, the average number of practices increased from year one to two to three, suggesting that the teacher’s implementation of the practices may have become more explicit. The open inquiry lesson presented by Hale-Hanes (2015) had five perceived practices, which was equal to other guided inquiry lessons as described in other research studies (Emden and Sumfleth, 2016; Hale-Hines, 2015; Lanni, 2014; Laur et al., 2012; McNell and Pimentel, 2009). Therefore, results of the present study and previous studies suggest that students experience the most SEPs when they participate in an open inquiry lesson.

The difference between the average number of SEPs perceived in the structured inquiry and open inquiry lessons should be noted. The average number of SEPs increased across the years of the study. In year one the difference was 0.1 average SEPs, in year two the difference was 1.3 average SEPs, and in year three the difference was 1.9 average SEPs. One possible reason this may have occurred is because the first author was gaining experience with SEPs as a teacher, and therefore, was more explicit with them during instruction. While science instruction has evolved in K-12 classrooms, science educators must respond by preparing future science teachers to be able to identify, understand, use, and teach students the science and engineering practices. Veteran teachers however, may use open inquiry teaching strategies as a bridge to the three-dimensional Framework for Science Education specifically the science and engineering practices. While using open inquiry teaching strategies provides an opportunity to engage in the SEPs they must also be explicitly taught. As teachers clearly define and help students identify the SEPs, the students understanding of the SEPs increases.

An important implication for K-12 science teachers and science educators from these findings is that students perceive more of the NGSS scientific practices when they participate in inquiry lessons as compared with non-inquiry and structured inquiry lessons. In addition, students may perceive more NGSS SEPs in open inquiry lessons as their teacher gains experience and becomes more explicit with the SEPs in their instruction. Therefore, as the NGSS becomes more and more prevalent in our school systems, it is important for science teachers, department chairs, and science educators to incorporate explicit instruction of the NGSS SEPs.

**Student understanding of NGSS SEPs**

The second question we sought to answer was which of the eight NGSS scientific practices do students report in a non-

<table>
<thead>
<tr>
<th>Lesson type</th>
<th>Asking questions and defining problems</th>
<th>Developing and using models</th>
<th>Planning and carrying out investigations</th>
<th>Analyzing and Interpreting Data</th>
<th>Using Mathematics and Computational Thinking</th>
<th>Constructing explanations and designing solutions</th>
<th>Engaging in Argument from Evidence</th>
<th>Obtaining, evaluating, and communicating information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-inquiry</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Structured inquiry</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Open inquiry</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
inquiry lesson, a structured inquiry lesson, and an open inquiry lesson? The two main findings discovered from the data were 1) students perceive some SEPs more frequently than others, regardless of the lesson type and 2) students perceive the same SEPs differently depending on the lesson in which they participate.

The results of the present study demonstrated that students perceive some practices more frequently than others. For example, the SEPs of Analyze and Interpret Data and Obtain, Evaluate and Communicate Information were always perceived in each lesson type. Oppositely, the SEPs of Developing and Using Models, Using Mathematics and Computational Thinking, and Engaging in Arguments from Evidence were not significantly perceived by participants in any lesson. While these were the practices that were identified for this lesson set, it is important to note that these may not be the SEPs identified for every non-inquiry, structured, or open inquiry lesson. These SEPs were identified for these specific lessons but might not be chosen every time the students participate in each respective level of inquiry. Nonetheless, science lessons designed around specific SEP’s do not automatically convey practices to students.

Teachers should be explicit about the SEPs they intend to incorporate in their lessons. This is supported by findings of Stanford et al. (2016) who showed that teachers who had experience implementing inquiry positively influenced the students’ perception and participation in the SEP as compared with other teachers who did not have experience implementing inquiry. When teachers have experience and are deliberate about the SEPs they choose to incorporate, the students are more successful at perceiving the practice. Educators of science teachers should encourage future science teachers to select two or three overarching SEPs in advance and specifically design the lesson to achieve those SEPs. This could enhance student understanding and ability to use the science and engineering practices. Students perceived some SEPs more frequently than others, suggesting that they are interpreting them differently depending on the lesson in which they participate. To develop a more coherent science curriculum for students, it is necessary to be more explicit about the teaching of SEPs. Classroom teachers and science educators need to define what it means to participate in the SEPs for students and check their understanding of the SEPs throughout the year.

The field of science education has moved from a once narrow focus on concepts and facts to a three-dimensional framework for science teaching and learning. Inquiry based pedagogies once purported via the National Science Education Standards provides an opportunity for teachers to use previously designed lessons and units to shift to the NGSS without losing the impact of well-designed units of instruction.

**Student understanding of NGSS SEPs definitions:** It was important to determine if students perceived the SEPs in the same way for each lesson in which they participated. By using the open-ended responses, it was determined that student perceptions of the SEPs changed based on the type of lesson that they participated in. While students identified the practice of Obtain, Evaluate, and Communicate Information in each of the three lesson types, their descriptions of this practice changed depending on the type of lesson in which they participated. For example, Student 11 described the practice of Obtain, Evaluate, and Communicate Information for both the non-inquiry and the open inquiry lesson. The student wrote in their description of the open-inquiry lesson, “It was more of obtaining and evaluating info, not really communicating, because it was independent. But we had to read the information and answer a few questions on it.” To describe the same practice in the open inquiry lesson, he wrote, “This was present because you had to get the information from the trials and communicate with your group to find the solution.” According to student 11, the practice still applied to the non-inquiry lesson even though he stated it was independent work and he did not have to communicate. Oppositely, in the open inquiry lesson he described the practice as communicating with his group in order to find a solution.

In conclusion, students can interpret the definition and meaning of the practices differently depending on the level of inquiry of the lesson. They are using what they know, with the options that they have, to make meaning of the practices, but this causes them to perceive the practice differently depending on the type of lesson. This finding provides further support for teachers and science educators to be explicit about the practices they are intending to incorporate in their lessons. Clearly defining each practice can help students identify and understand the practices in such a way that is appropriate for science learning. For example, student perceptions of the practice of Obtain, Evaluate, and Communicate Information could be different in English classes than Science classes. A clear conception of differences in each of the practices is necessary for student understanding and use of the practices. This is a necessary foundation for assessment and learning of the SEPs. This idea is supported by findings of Emeden and Sumfleth (2016) who demonstrated when specific NGSS SEPs are selected for and taught using inquiry methods; it was an accurate way to assess student’s participation and perception in those designated SEPs.

**Conclusions**

The adoption of new national standards impacts how and what is taught in science classrooms and during science teacher preparation programs. The research findings suggest teachers can provide access to the most NGSS SEPs possible when they are intentional about using higher levels of inquiry strategies for teaching and learning.
Transitioning between the previous and new standards has been a meaningful task for states, districts, and subsequently teacher preparation programs. Already states and districts are designing assessment systems to align to the national standards. Inquiry based pedagogies provide an opportunity for a continuous transition to the science and engineering practices of the Next Generation Science Standards. If veteran teachers were around for the adoption of the NSES standards, their previously designed units can be a great foundation for the development of new curriculum and assessments. Science teacher preparation programs can better prepare future science teachers by providing a historical context for the development of NGSS standards and inquiry-based pedagogies as a best practice in science teaching and learning. Our goal is to prepare the next generation of science teachers and ultimately prepare the next generation of science learners.

ACKNOWLEDGMENTS

We thank the students from York High School for being such willing participants to help us learn more about how to improve the teaching of science to meet the needs of the 21st century learners and the practices of science educators.

REFERENCES


