ABSTRACT
This article illustrates how a seventh-grade life science unit connects to the Science and Engineering Practices and Nature of Science in the Next Generation Science Standards and used science fair projects as a context for students to solve problems and understand how authentic science is done. We outline how student interests drive the development and presentation of science fair projects and discuss each component of a science fair project to reflect the practices and nature of science and how we support students along the way. The article includes images of students and of their work for science fair projects.

Key Words: middle school science fairs; NGSS science and engineering practices; nature of science; student interest.

Introduction
This article illustrates how independent science fair projects in a seventh-grade life science unit connect to both the Science and Engineering Practices (SEPs; Table 1) and the Nature of Science (NOS; Table 1) in the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). Independent science fair projects are investigations in which students, individually or in small groups, seek to investigate phenomena of interest to them with assistance from their teacher or a mentor (Bunderson & Anderson, 1996). The SEPs are ways that authentically unite the processes used by scientists to understand the natural world. The NOS is an understanding of “science as a way of knowing” (Lederman, 1992, p. 331). As presented in appendix H of the NGSS, the NOS refers to the context in which science is done, including the core values and the assumptions that are part of the development of scientific knowledge (Lederman & Zeidler, 1987).

Science fairs are venues where students’ science and engineering projects are evaluated and celebrated (Bencze & Bowen, 2009). In their projects, students include the SEPs to answer testable questions (STEM Education Coalition, 2012) and thereby also illustrate many components of the NOS. Science education research has documented positive learning outcomes for students participating in science fairs (Schmidt & Kelter, 2017; Koomen et al., 2018), supporting their value in science education (Figure 1).

At the beginning of the school year, an insect investigation laid the foundation for the SEPs and the NOS in the first author’s seventh-grade life science classroom in a small rural school district in the Upper Midwest. A monarch butterfly unit introduced students to the SEPs (asking questions, developing models and using mathematics, information and computer technology and computational thinking; NGSS Lead States, 2013). The unit was based on lessons adapted from the “Monarchs in the Classroom” curriculum (Oberhauser & Goehring, 2009), including lessons on rearing, observing, collecting data accurately, and developing a graph (Appendix 1; Appendices 1–7 are available as Supplemental Material with the online version of this article). To interpret graphs, students used question frames from the Biological Sciences Curriculum Study (BSCS) “Identify and Interpret” strategy: “What do you see?” and “What does it mean?” For example, students described what they saw in Figure 2 (possible answers might be a line that goes to the upper right, or number of days, etc.). Next, students explained what it means when the line goes up (the mass of the larva is increasing or there is a positive slope). Then the class discussed how this positive slope represents a model of larval growth over time. The insect unit ended in a mealworm lab that supported students in developing a testable question, a hypothesis, and a plan for carrying out an investigative study (Appendix 2).

Application of SEPs & NOS in Science Fair Projects
Our students used a teacher-created template (Appendix 3) to design their projects. They eventually used Google Slides for each section of their project: title, introduction, question/hypothesis, methods, results, discussion, and conclusion. The slides were printed out and placed on a trifold board for presentation at the science fair. In the
sections that follow, we illustrate how science fair projects integrate the SEPs and the NOS, through three randomly selected science fair projects by middle school students (projects 1 and 3 were each completed individually; project 2 was completed by a pair of students) seeking to answer the following questions.

(1) Project 1: What effect does tannic acid in the St. Louis River have on duckweed (Lemna minor) growth while under stress from motor oil pollution?

(2) Project 2: What effect does gender have on who is willing to eat an edible insect?

(3) Project 3: What effect do artificial sweeteners have on growth of probiotic bacteria?

Abstracts for all three projects are found in Appendices 4, 5, and 6. Our instruction included informal connections to the SEPs and the NOS rather than an explicit emphasis. In the next sections, we use the scientific form of the project to discuss the process students engaged in to complete their projects (Koomen et al., 2018).

○ Identifying a Topic

As an introduction to the research projects, students (1) listened to former students (8th–12th graders or alumni) share their completed projects and experiences, (2) chose a topic of personal interest, and (3) received a template for planning their investigation that builds from the foundation they experienced with the insect investigations.

Former science fair students talked to the middle schoolers about their projects, including what they did, what they learned, and why doing the project was worthwhile for them. They also shared how they took an idea based on their interests to develop an investigation (Figure 3).

In small groups, students identified five potential science fair topics they were interested in exploring. Next, they spent a week learning about those five topics, using handheld electronic devices to document links to our learning management system. After students identified a topic of interest, a teacher screened the topic idea for efficacy as a science fair project, and the students received a template for the project (Appendix 3), building on the foundational experience of the insect investigations.

○ Developing Testable Questions & Hypotheses

SEPs: Asking questions and defining problems. After selecting a topic, students continued to look up background research on their topic.
for the introduction to their science fair project. For example, the student author of Project 1 was interested in recent news reports about oil spills and how those spills impacted the growth of aquatic plants like duckweed. Her background research included information on density of oils, how contaminants like oil are taken up into plants, and the basic biology of duckweed as described in her introduction slide (Figure 4; note that all student work reproduced in this article is shown in its original form, including some errors and typos). This helped her define the problem and eventually became part of her introduction to the science fair project. The teacher showed students how to use EasyBib to write citations.

We modeled how to develop a scientific research question using the following format: What effect does _____ (independent variable; what I changed) have on _____ (dependent variable; what depends on the independent variable)? In Project 1, all of the student’s research helped identify independent variables (tannic acid solutions, water type, and motor oil solution) and dependent variables (percentage change in frond production) that could be studied. Identifying the variables led her to write a testable question (“What effect does tannic acid have on Lemna minor while under stress of motor oil?”) and hypothesis: “If the duckweed is grown in the St. Louis River with extra tannic acid, duckweed growth will be positively affected when compared to duckweed grown in the St. Louis River control without tannic water.”

NOS: Science addresses questions about the natural and material world. Science fair projects require a testable question that leads to a scientific investigation or (in engineering topics) the definition of a problem, typically generated by something students have observed or wondered about. In our experience, students tend to choose projects that require easily accessible materials. Examples include distilled water and motor oil (Project 1); edible insects ordered online and Google Forms survey tools (Project 2); and Petri dishes, pipettes, and an incubator from the school science lab (Project 3). As in the NOS matrix performance expectations, these student questions were defined by the constraints of available materials and the middle school science background to answer questions about the natural and material world and were limited to explanations that rely on observation and empirical evidence (NGSS Lead States, 2013, appendix H).

Methodology

SEPs: Planning and carrying out an investigation. Once students had identified an area of interest and developed a research question and hypothesis, they planned and carried out an investigation “to produce data to serve as the basis for evidence that met the goals of an investigation” (NGSS Lead States, 2013, appendix F). Students developed the rationale detailing why their study was important as they determined independent, dependent, and control variables. They developed step-by-step instructions; a description of materials; a plan to collect data, with consideration of measurement units (grams/liters, etc.); and a plan to organize data, choosing the style of graph appropriate for their study (Figure 5).

NOS: Science investigations use a variety of methods. While completing their science fair projects, students used a variety of...
Project 2 Method
- Independent variable – gender; Dependent variable - eating choice
- Constant – survey
- Step-by-step
  - A 5-minute 6 question online password protected survey was developed in Google forms.
  - 183 middle school students took the survey, with informed consent.
  - Edible insects ordered online were obtained.
  - In the 7th life science classroom edible insects were offered to all students, the ingredients were reported.
  - The students willingness to touch or eat them was recorded. The students were not required to eat them.
  - This study was done to determine if gender had an effect on the student volunteers’
    willingness to eat nutritious insects

Figure 5. Methods written by a pair of students for an independent research project.

Project 3: Models

![Figure 6](image)

Figure 6. A student-generated graph models a phenomenon for an independent research project.

methods (NGSS Lead States, 2013, appendix F) to answer their testable questions, choosing discipline-specific methods and tools (NGSS Lead States, 2013, appendix H). These specific practices “are guided by a set of values to ensure accuracy of measurements, observations, and objectivity of findings.” The student in Project 1 used the convention of making water dilutions with oil to measure how different concentrations of motor oil affect duckweed. The students who surveyed the effect of gender on willingness to eat edible insects (Project 2) used the social science practice of collecting participant consent forms. The students working with live organisms to test the effects of artificial sweeteners on bacteria (Project 3) adhered to safety guidelines and used statistical tests like analysis of variance (ANOVA) to evaluate their results.

SEPs: Developing and using models. Drawing from our previous work modeling the growth and development of monarchs through graphs, students developed a model that represented their research findings. For example, in Project 3, students developed a model (Figure 6) to describe the effect of artificial sweeteners on bacteria by hypothesizing that the higher the level of artificial sweetener, the less probiotic bacteria would grow in the agar plate. Students communicated this model by creating a graph to show the number of bacteria that grew in water, different dilutions of artificial sweetener, different dilutions of sugar, and probiotics – a graph that effectively describes a phenomenon (NGSS Lead States, 2013, appendix F). The graph displayed the evidence of the effect of a variable, the presence of artificial sweeteners, on the system of probiotic bacteria growth in a Petri dish.

NOS: Scientific models, laws, mechanisms, and theories explain natural phenomena. As noted above, the students in Project 3 developed a model (Figure 6) that described the phenomenon of the effect of artificial sweeteners on bacteria. They hypothesized that there would be less probiotic bacteria with the increase of an artificial sweetener. Their hypothesis was an example of how an “idea may contribute new knowledge for the evaluation of a scientific theory” (NGSS Lead States, 2013, appendix H).

○ FINDINGS

SEPs: Using mathematics, information and computer technology, and computational thinking. After students had completed their data collection, they used mathematics, computational thinking, and computer technology to organize the data into tables or graphs, building on prior work with the monarch line graphs. Students chose the appropriate graph to use to display their data. For some projects, students used inferential statistics, including ANOVA and the relevance of a P-value. The mathematical representations were used “to support scientific conclusions and design solutions” (NGSS, 2013, appendix F). For example, Project 2 students developed bar graphs to illustrate percentages of each gender willing to try eating insects (Figure 7) with error bars representing the variability of the data.

SEPs: Analyzing and interpreting data. Students created a data collection table and entered the data as they were collecting them. When they were finished collecting data, students converted the table into a graph that included a title and labeled axes. Building from their prior knowledge and research, they used the BSCS tools to interpret the data by observing patterns, thus supporting the NGSS standard that calls for analyzing and interpreting data to provide evidence for phenomena (NGSS Lead States, 2013, appendix F). In Project 2 (Figure 7), students placed gender on the x-axis and the percentage of people willing to try eating an insect on the y-axis. The template prompts students to think about what phenomena to measure and why, along with describing what they observed.

As noted above, students used the BSCS sentence frames to analyze and interpret their data. For example, in Project 3, students displayed their data in figures (Figure 6 and 8). In the results section (Figure 9), they interpreted what their graphs meant. In the results slide (Figure 9), they described the purpose of their study and explained the relationship between dependent and independent variables in their graph, again addressing the standard to “analyze and interpret data to provide evidence for phenomena” (NGSS Lead States, 2013, appendix F).

NOS: Scientific knowledge is based on empirical evidence. In Project 2, students obtained data by receiving formal participant consent before participating in the survey. Students presented their data in a bar graph to depict their findings in Figure 6 above. Bar graphs were used to follow the “common rules” of obtaining and displaying tabulated or counted data in bar graphs (NGSS Lead States, 2013, appendix H).
Conclusions

SEPs: Constructing explanations. In our teaching, students used a modified version of the explanation framework developed by McNeill & Krajcik (2012), which assisted students in constructing explanations from their data analysis using claims, evidence, and reasoning arguments. The evidence referred to data that supported their claim or conclusion to a problem. Reasoning referred to scientific principles to describe how the evidence supports the claim. As students constructed explanations, they determined the hypothesis that was supported by the data/evidence in their investigation. Next, students substantiated the claim with quantitative reasoning, as illustrated in the Project 3 discussion section (words in square brackets inserted by authors):

The original hypothesis was if the normal flora (probiotics) of the small intestine are treated with saccharin (an artificial sweetener), then the probiotics’ ability to metabolize glucose will be affected. The hypothesis was supported [claim]. Overall there were significantly fewer bacteria colonies on the saccharin treated probiotic plates when compared to the sugar treated bacteria, ANOVA p<0.068 [evidence, reasoning]. (Project 3 Board)

Their scientific explanation was based on evidence obtained from their experiments that the metabolism of probiotic bacteria would be affected by the presence of saccharin. The explanation aligned with the NOS assumption that “theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future” (NGSS Lead States, 2013, appendices F and H).

SEPs: Engaging in argument from evidence. To engage in argument from evidence, students contextualized their results within the scope of their investigations by referring back to the background research literature they collected at the beginning of the study. In their project conclusion, they presented “a written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem” (NGSS Lead States, 2013, appendix F), as illustrated in the conclusion for Project 1 (Figure 10, with author-inserted brackets identifying claim, evidence, and reasoning; McNeill & Krajcik, 2012).

Each project’s evidence-based “written argument . . . supports an explanation or a model [e.g., oil on the surface of water will impact the growth of duckweed] for a phenomenon” (NGSS Lead States, 2013, appendix F). For example, the underlined text in Figure 10 incorporated other key elements of the NOS (e.g., “Scientific knowledge is based on empirical evidence”) as students built their outcomes (oil negatively affected the duckweed) on the basis of logical and conceptual connections between evidence and explanations (e.g., the layer of oil cuts off oxygen exchange and diminishes sunlight, reducing the plant’s ability to photosynthesize; NGSS Lead States, 2013, appendix H).

SEPs: Obtaining, evaluating, and communicating information. Finally, the students wrote an abstract (Figure 11) summarizing their project by using a template (Appendix 7). In the abstract they described how they had obtained, evaluated, and communicated information about their scientific study. When they went back to their background research, they “synthesize[d] information from multiple appropriate sources” (NGSS Lead States, 2013, appendix F).
NOS: Science is a way of knowing. Throughout the process of developing their science fair projects, our students built an understanding that “science is both a body of knowledge and the processes used to add to that body of knowledge.” Their initial research, presented in their introduction, allowed them to understand science knowledge about their topic and how their experiment related to that body of knowledge. The discussion and conclusion sections of their projects brought their research full circle, with students reflecting on who would benefit from the results and what they would do in future iterations of the study. Those ruminations allowed students to think critically about the elements of their investigation.

**Conclusion**

Independent science fair projects provide an opportunity for students to do science “like scientists” and to explain the results of their projects just as scientists explain their own work. In other words, these projects connect students to the practices of science and the nature of science, and students develop an awareness of how science helps to solve problems and build knowledge. Recent research has documented the ways in which science fair projects promote interest in STEM educational endeavors and careers, thus constituting valuable experiences for students (Koomen, Hedenstrom & Moran, in review).

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