## Classroom Activities

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Experiments, laboratory activities, demonstrations, and other descriptions of the use of chemicals, apparatus, and instruments are illustrative and directed at qualified teachers. Teachers planning to use materials from MSTA Journal should consider procedures for laboratory and classroom safety to meet their local needs and situation. MSTA Journal cannot assume responsibility for uses made of its published material.
In this article we present a 5E lesson on community structure and ecological succession that addresses middle school performance expectations of the Next Generation Science Standards (Achieve, Inc. 2013). Specifically, students investigate a fictitious forest to learn that communities can be described by their species composition and abundance, physical structure, and dominant species. They also learn that succession is a change in these characteristics over time. In a forest for example, trees grow in girth and height, and over time the canopy thickens and reduces light levels on the forest floor. This leads to more shade-tolerant species replacing those that cannot tolerate the changing conditions. Finally, the lesson highlights integration of the three NGSS dimensions within performance expectations by having students analyze data and use evidence to explain the cause of changes in the pattern of tree species in a forest. This inquiry-based ecology lesson is designed to take place entirely inside the classroom, which is particularly helpful in suburban and urban schools without access to natural areas. In addition, the lesson can be used as a primer for students prior to any outdoor experience so they can better understand what they observe.

Objectives

Upon completion of this lesson students will be able to:

• Describe community structure using terms such as species composition, species abundance, physical structure, and dominant species.

• Define succession as a change in community structure over time.

• Explain the role of disturbance in succession.

• Describe how the age, height, and shade-tolerance of trees influence the succession of a forest community.

• Define climax as a mature community that remains relatively unchanged over time, in the absence of a major disturbance.

Engage

In this phase of the lesson students are introduced to three forest communities and asked to consider whether they are the same or different forests. Before beginning, make sure students are comfortable with the concepts of species and population. They should understand that a community is several populations of different species interacting in a particular area. Begin by having students look at the Community Profiles of Forests A, B, and C. Explain that these diagrams show a side view of three forests and that each community consists of several populations of different tree species. Point out the key for the five tree species: American beech, bigtooth aspen, flowering dogwood, Northern red oak, and sugar maple. Ask students if they think the three profiles are really the same or different forests. Remind them that scientists reach conclusions based on evidence, and encourage them to support their views by citing specific observations. For example, they may point out that the trees are larger in Forests A and C. Or they may note that aspen is present in Forests A and B, but not
C. Observations like this can lead to differing opinions about whether there is actually one, two, or three distinct forests. Tell students that before they can decide, they need to learn how scientists describe communities. (The profiles represent the same forest at different stages of succession, but keep this to yourself for now.)

EXPLORE
In this phase of the lesson students collect and analyze data to learn components of community structure. Tell students that forest ecologists are scientists who study forests and that one of the things they look at is what species compose the community. Have students emulate these scientists by recording the tree species in each forest (A, B, and C). The species students will find are presented in the Community Structure Worksheet. Students may argue that all three forests have essentially the same species and thus are really the same, except for aspen missing from Forest C. Tell students that they have investigated the species composition of each forest, but there are other aspects of community structure to consider. For example, measuring the abundance of each species provides more information than simply recording species composition. Ask students what the most common species are in each forest. Define species abundance as the quantity of a particular species in a community, and have students record this for each species in all three forests. Some students may argue that beech and maple are the most common species in all three profiles, making them the same forest (community structure worksheet). Others may insist that the large number of aspen in Forest B makes it different from the other forests. Ask students to consider which species contribute to the canopy layer in each forest. Describe physical structure as the vertical layers of trees in a forest, another component of community structure.
It may help to use the analogy of the first and second floors of a house. Tell students this vertical layering in a forest provides a diversity of habitats for animals and other organisms. The community structure worksheet shows aspen in the canopy layers of Forests A and B, beech and maple in the canopies of Forests A and C, and oak in the canopy layers of all three forests. Students may argue strongly for how many different forests there are at this point, likely two or three. But insist that there is another component of community structure they should take into consideration before deciding.

### Community Structure Worksheet (Key)

**Species Composition**

Directions: Place an “X” in the box if a species is present in Forest A, B, or C.

<table>
<thead>
<tr>
<th>Species</th>
<th>Forest A</th>
<th>Forest B</th>
<th>Forest C</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Beech</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Bigtooth Aspen</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Flowering Dogwood</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Northern Red Oak</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Sugar Maple</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

**Species Abundance**

Directions: Record the number of trees for each species that exists in Forest A, B, and C.

<table>
<thead>
<tr>
<th>Species</th>
<th>Forest A</th>
<th>Forest B</th>
<th>Forest C</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Beech</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Bigtooth Aspen</td>
<td>2</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Flowering Dogwood</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Northern Red Oak</td>
<td>5</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Sugar Maple</td>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

**Physical Structure**

Directions: Record the number of trees for each species in the canopy layer of each forest.

<table>
<thead>
<tr>
<th>Species</th>
<th>Forest A</th>
<th>Forest B</th>
<th>Forest C</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Beech</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Bigtooth Aspen</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Flowering Dogwood</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Northern Red Oak</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Sugar Maple</td>
<td>3</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>
For this portion of the lesson make sure students are comfortable with the formula for the area of a circle \((\pi r^2)\). Refer students to the Basal Area Diagrams, and tell them that they represent a bird's eye view of each forest from above. The trunks have been cut, and each circle represents the cross-sectional area of the trees in the forests of the original community profiles. Explain that the cross-sectional area of each trunk is called basal area, and this is a good estimate of the biomass of each tree. Ask students which forest has the greatest total biomass. Which has the least? They should easily conclude that Forest C has substantially more biomass than the other two forests, and that Forest B has the least. Ask them which species have the most biomass in each forest. They should see that the species with the most biomass differ from forest to forest. Beech, maple, and oak have the most in Forest A, aspen and oak the most in forest B, and beech and maple the most in Forest C. Tell students that biomass contributes to another component of community structure. Introduce the term, dominant.
species, as the largest and most abundant species in a community. Ask students to use the data they collected in the community structure worksheet and the basal area diagrams to decide what the dominant species are in each forest. Beech and maple are the most abundant species in Forest A, followed closely by oak. These three species also make up the canopy layer of Forest A and contribute the most to biomass. Beech, maple, and oak are the dominant species of Forest A. Aspen, beech, maple, and oak are equally abundant in Forest B, but only aspen and oak reach into the canopy layer, and they also contribute the most to biomass. Aspen and oak are the dominant species of Forest B. In Forest C beech and maple are the most abundant, comprise the majority of the canopy layer, and contribute the most to biomass. They are the dominant species of Forest C. Explain to students that the dominant species have a great impact on a community, providing much of the habitat and resources for wildlife, such as food and nesting sites.

**EXPLAIN**

In this phase of the lesson students develop an initial understanding of succession. But first it is time to confess. Have students look at the community profiles again, and tell them that they represent the same forest in three different time periods. Ask students to name the correct chronological sequence from young to more mature forest (B, A, C). They should see some of the oak and aspen that dominate Forest B present in the canopy of Forest A. Eventually these species decline in number and are replaced by beech and maple in the canopy of Forest C. Define succession to students as a change in community structure over time. Ask them how the community structure of the forest changed from B to A, to C. Remind students to use the ecological terms they have learned and the data they collected, referring them to the community profiles, community structure worksheet, and basal area diagrams. Help them see that species composition and abundance changed as aspen and oak became less abundant, with aspen eventually disappearing from the forest. The physical structure of the forest changed as trees grew taller and a thicker canopy developed. The dominant species changed from aspen and oak in the young forest to beech and maple in the mature forest. Remind students that the dominant species are the largest (canopy layer; biomass) and most abundant species in a community. All of these changes to community structure (species composition, species abundance, physical structure, and dominant species) constitute the succession the forest went through over time. Ask students if they think the mature forest (C) could ever look like the young forest (B) again. They will likely reply that it could if there were a forest fire. Introduce the concept of disturbance to students, providing examples such as fire, logging, or a severe wind storm. Tell students that succession is the process a community goes through following a major disturbance. This lesson addresses a common misconception students have that communities change little over time (D’Avanzo 2003).

**ELABORATE**

In this phase of the lesson students extend their understanding of succession, specifically why it happens. Explain to students that recognizing patterns in nature is important, but that understanding why these patterns occur is even more powerful (cause and effect). Tell them to continue to act as forest ecologists by examining different characteristics of each tree species in the Tree Field Guide adapted from Barnes and Wagner (1981). This guide contains information on how tall the trees grow, how long they live, and their ability to tolerate shade. Define shade-tolerance as the ability to withstand low levels of light under the canopy. Students should record each species’ height, age, and shade-tolerance in the Tree Ranking Worksheet. Ask students why dogwood will never be a dominant species in the forest. They should recognize that, although it is a long-lived, shade-tolerant species, it does not grow above 15 meters.
and will never contribute to the canopy. Have students explain why aspen will never be a dominant species in the mature forest. Help them see that aspen is a relatively short-lived tree that is shade-intolerant. So as the canopy thickens and reduces light levels below it, aspen eventually stops growing. Aspen trees do contribute to the canopy layer of the mid-stage of succession (profile A), but they began growing in an early stage of succession (profile B) with a more open canopy and higher light levels, and are not present in the mature forest (profile C). Students may wonder about the large oak in the canopy of the mature forest. This remnant oak is a long-lived species that started growing in an early stage of succession, and will remain in the canopy layer until it dies. However, because oak is less tolerant of shade, it will not persist as a dominant species in the forest. Explain to students that they can determine which species will continue to grow and survive in the mature forest (profile C) by looking at the forest floor to see which species are reproducing. They should note that only beech, dogwood, and maple are present in these low light conditions. We have already discussed how dogwood does not grow tall enough to reach the canopy layer. So the dominant trees of this forest will continue to be beech and maple, as younger seedlings and saplings of these species grow larger and eventually reach the canopy. Define climax to students as the stage of succession in which a community has matured and will remain relatively unchanged in the absence of a major disturbance. Profile C represents the climax stage of this community, accurately described as a beech-maple forest.
EVALUATE

Assessment occurs in each phase of the lesson as students provide evidence for how many forests they think are represented in the community profiles (Engage); analyze data from the community structure worksheet and basal area diagrams to develop an understanding of the components of community structure (Explore); learn to define succession as a change in this structure over time initiated by disturbance (Explain); and interpret characteristics of each species in the tree field guide and tree ranking worksheet to form an explanation for why succession occurs (Elaborate). A more detailed version of this lesson is available on the Grand Valley State University webpage of Christopher Dobson (http://www.gvsu.edu/biology/christopher-dobson-40.htm) under 5E Lesson Plans. It contains full size worksheets and diagrams that can be easily printed for students or turned into overheads for use in instruction. It also provides specific formative assessments in each phase of the lesson, as well as a summative quiz at the end.

INTEGRATION OF NGSS DIMENSIONS

The Next Generation Science Standards are based on the Framework for K-12 Science Education (NRC 2012) and represent a substantial improvement over the previous science standards (NRC 1996). NGSS standards contain multiple performance expectations, each integrating three dimensions (science and engineering practices, disciplinary core ideas, and crosscutting concepts). The Performance Expectations box below shows the expectations addressed by this lesson (MS-LS2-1, MS-LS2-2, and MS-LS2-4). The core idea in all three is Interdependent Relationships in Ecosystems (LS2.A). The bolded portions of each expectation show the integration of science practices and crosscutting concepts with this core idea. Throughout the lesson students analyze and interpret data, construct explanations, and engage in argument from evidence (science practices). They also identify patterns and learn about the cause and effect relationships resulting in those patterns (crosscutting concepts). See Bybee (2011) for a more detailed explana-
tion of science practices and Duschl (2012) for a thorough discussion of crosscutting concepts.

We have presented this inquiry-based lesson as an engaging way for your students to learn about community structure and ecological succession, addressing specific NGSS performance expectations. By analyzing data and providing evidence for conclusions, students develop the science practices that we want, while learning content in the context of concepts that transcend any one science discipline, such as patterns and cause and effect. This lesson can be used as a stand-alone activity or as a preliminary exercise for some subsequent outdoor experience. Either way, it is our hope that this lesson will help your students see the forest for the trees!

REFERENCES
Achieve, Inc. 2013. Next Generation Science Standards. Achieve, Inc. on behalf of the twenty-six states and partners that collaborated on the NGSS.

Performance Expectations

MS-LS2-1. **Analyze and interpret data** to provide evidence for the **effects** of resource availability on organisms and populations of organisms in an ecosystem.

MS-LS2-2. **Construct an explanation** that predicts **patterns** of interactions among organisms across multiple ecosystems.

MS-LS2-4. **Construct an argument supported by empirical evidence** that changes to physical or biological components of an ecosystem **affect** populations.

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<th>Crosscutting Concepts</th>
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<td>LS2.A. Interdependent Relationships in Ecosystems</td>
<td>Patterns</td>
</tr>
<tr>
<td>Constructing Explanations</td>
<td></td>
<td>Cause and Effect</td>
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<tr>
<td>Engaging in Argument from Evidence</td>
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Modeling with Magnets: Using Knowledge is More Than Knowing the Right Answer

By Mark Olson, Assistant Professor of Science Education, Oakland University; James DeHaan, Physics Teacher, De La Salle Collegiate High School

Abstract
The Next Generation Science Standards (NGSS) differ in important ways from previous standards documents. One such difference is the emphasis on, and explicit attention given to, the practices of science. We look at how one of these practices—the practice of modeling—builds upon ideas contained in the Michigan High School Content Expectations. We share an activity using ordinary magnets that illustrates how the practice of modeling can be challenging for students and why modeling as a classroom practice is important.

Introduction
The views of science teaching and learning found in the Framework for K-12 Science Education (National Research Council, 2012) and in the Next Generation Science Standards (NGSS) (Achieve 2013) introduce a new emphasis on what are called the eight practices of science. We show how one such practice—the practice of modeling—builds upon and extends ideas found in the Michigan High School Content Expectations in Science (Science HSCE). Guided by this work, we illustrate how an engaging activity we’ve used with high school physics students involving ordinary magnets can be a powerful introductory learning opportunity for modeling as a science practice. We show that even though students “knew” the relevant elements of the model of magnetism and had data that fit that model, they had difficulty in explaining the phenomena accurately. In other words, they had difficulty engaging the practice of modeling.

The Practice of Modeling
It is a well known principle of effective instruction that students enter classrooms with ideas that may differ from scientific ideas and that these ideas need to be meaningfully engaged in order for students to learn with understanding (Donovan & Bransford, 2005). The ideas that students have about science are often in the form of mental models. The Frameworks describe these mental models as “internal, personal, idiosyncratic, incomplete, unstable, and essentially functional” (p.56, NRC, 2012). Such mental models are contrasted with conceptual models that are the explicit representations of science ideas that can be simply considered as a “set of ideas about how something in the world works” (p. 36, Campbell, Nelson, & Oh, 2013). The practice of modeling includes using an explicit conceptual model to account for the patterns and data associated with some phenomena. This means that for students, the practice of modeling means productively aligning their mental models with explicit conceptual models. To be effective, teachers need to provide opportunities for students to work through the challenges of such an alignment process.

Modeling as a practice has been helpfully represented in the diagram Knowledge and Practices of Model-based Reasoning from the Science HSCE:
The practice of modeling can engage both the inquiry and using knowledge sides of the triangle following the arrows up and down. Again, we use the definition of a conceptual model from (Campbell, et al. 2013) to mean the set of ideas about how something in the world works. Depending on which side of the triangle you are targeting, you will engage modeling as either constructing ideas or using and applying ideas about how something in the world works.

From the inquiry side of the triangle, modeling is the practice that starts with data and patterns and aims to construct a set of ideas to explain those patterns in data. These ideas used to explain phenomena are the model or theory at the top of the triangle. When moving up the left side of the triangle, we are addressing the question: What set of ideas explains how this phenomena works? The arrow on the inquiry side of Figure 1 represents model construction.

Modeling approached from the using knowledge side of the triangle is the practice of using a set of ideas, i.e. a conceptual model, to account for patterns in the data. The question that motivates movement down the right side of Figure 1 is: How does the model account for the patterns in the data and how well can we use this model to explain phenomena? The arrow on the using knowledge side represents model use and application.

There are a number of recent articles that attend to the modeling approach from the inquiry side (see for example, the recent September, 2013 special issue of The Science Teacher). We focus our attention in this article on the using knowledge side of the triangle. We do so in order to emphasize the need for students to build their capacity to use model-based reasoning in order to make their science knowledge meaningful. As we will show in the magnets activity, even when students had access...
to both an accurate conceptual model and accurate data they did not engage in model-based reasoning. Instead, students used other sense-making strategies such as factual recall or as has been described elsewhere, geometric associations of polarity (Olson, in press). Most students’ sense-making strategies tended to overlook data when explaining phenomena.

THE MAGNETS ACTIVITY

The magnets activity uses an everyday, ordinary magnet of the type shown in the image below. Such magnets are found in many classrooms in long stacks, or stuck on metal cabinets, refrigerators, and elsewhere.

Students were given an unlabeled ceramic rectangular magnet of the following shape and polarity:

![Face-polarized rectangular magnet](image)

The students were asked to predict where the poles would be and what the field lines would look like. They were also given a small compass to detect the direction of the magnetic field lines.

Students began the activity knowing the properties of magnets: Magnets have north and south poles and magnetic field lines connect one pole to the other. They knew that like poles repel and unlike poles attract. They also observed that the magnets stacked on their faces and students likely had played informally with magnets like these previously.

![Student uses a compass to create a map of the directions of the magnets’ field lines.](image)
However, the rectangular magnets given to the students are not polarized on the ends as most had presumed, but instead these magnets are polarized on the largest faces of the rectangles (Figure 2). Iron filings in the images in Figures 6 and 7 show the different orientations of the field lines and the pole locations of end-polarized and face-polarized magnets, respectively.

The observations we discuss are based on work with 120 high school physics students over 7 class periods in two different high schools. The second author was a guest-teacher for these sessions. Our aim is to illustrate why the practice of modeling in the context of using knowledge: application (Science HSCE) is a worthy goal of instruction.

**WHAT WE LEARNED**

Students made initial predictions about the locations of the poles for their rectangular magnets. Only a tiny fraction of the students predicted a face-polarized orientation. This is entirely to be expected as typical representations of magnetic poles in rectangular magnets are almost certainly of this type. In fact, we are aware of no textbooks that portray images of face-polarized rectangular magnets. This point is quickly corroborated by a quick image search of the World Wide Web for magnetic field lines.
After students completed their individual field line maps and drawing lines to indicate the field direction, students were placed into groups and asked to prepare a whiteboard presentation of their investigations and share with the class what they had learned. Many of these groups persisted in representing the field lines consistent with the initial predictions of the poles located at the ends. Below are several images of whiteboards from groups that accurately represented their data (the small arrows indicating field direction from the compass direction). The presentations also demonstrate a persistent commitment to pole locations at the short ends of the magnets. Such pole locations and the field line maps drawn aligned with the typical field representations of bar magnets and are consistent with most student predictions.

The diagrams in Figure 8 show that students were not correctly connecting the field direction data and the overall mapping of field lines. Some groups were able to connect the field direction data accurately, as in Figure 9 below.

**FIGURE 8. WHITEBOARD PRESENTATIONS OF FIELD LINES INCORRECTLY MAPPED.**

**FIGURE 9. WHITEBOARD PRESENTATION OF FIELD LINES CORRECTLY MAPPED.**

**DISCUSSION**
Because these examples suggest students may overlook data and model-based reasoning in favor of other sense-making strategies, it is important for teachers to provide opportunities for students to use their understandings of conceptual models to explain patterns in data.
DOING SCHOOL: GETTING THE RIGHT ANSWER IN SCIENCE CLASS

It might be challenging to identify a content topic for which high school students have had more exposure across their school science experiences than magnets. Magnets are a ubiquitous part of the elementary science curriculum and are often used in middle schools. Magnets are part of students' everyday experiences. The conceptual model of magnetism is straightforward: magnets have north and south poles, magnetic field lines connect these poles, and like poles repel and opposite poles attract. Despite the familiarity of this conceptual model, it is clear that the practice of modeling requires more than knowledge of the model's parts. Modeling as a practice requires explicit attention to data. However, for many students, data were not a primary resource for explaining their observations.

We wonder to what extent “knowing what the answer should be” influences students? The common use of bar magnets makes it likely for students to presume that the north and south poles are at the ends of the magnet. This geometric association between shape and polarity may be stronger than efforts to reason from evidence. It is significant that in an activity in which students were expressly asked to substantiate their claims with evidence—many students chose to rely on what they thought was the correct answer rather than follow a data-based interpretation of the ideas.

We suggest two hypotheses to examine in future uses of this kind of magnets activity. We first articulate the hypotheses we aim to examine with groups of students in the future, and then we comment on how we might use the magnets activity to explore them.

1. Students were unsure about the expectations for “what counts” as an acceptable response to this activity. If students interpreted the activity to be merely a confirmation activity for an answer they already know—then disregarding contradictory evidence is a smart move. A student would reasonably select for a correct answer over a counter-intuitive answer simply because the data may have been erroneous.

2. Students did not understand what it means to explain a phenomena with respect to a model. That is, students did not see the task as an opportunity to engage the practice of modeling as using a set of ideas about magnetism to explain the patterns in data. This hypothesis also includes examining to what extent the data generated in the investigation were a meaningful component of the modeling process.

THE PRACTICE OF MODELING AS DEPICTED IN THE FRAMEWORKS AND THE NGSS

The NGSS emphasize the importance of students constructing their own models. While we would agree that this construction, or “invention,” connotation of the practice of modeling is important—our experiences suggest modeling is also importantly about how a student uses a model. That is, a teacher can’t “give” a student a model sufficient that the student would simply “understand” how to employ that model to account for patterns in data. The practice of modeling is the ability to use a set of ideas to explain phenomena.

The extensive literature on student prior-conceptions (e.g. Driver, et al., 2013) is premised on the idea that students develop mental models or representations that may or may not be scientifically accurate. The conceptual change pedagogical approach (Duit & Treagust, 2003) was developed to engage students in the process of explicating erroneous initial student thinking as a necessary condition for building more accurate mental models of the phenomena.
In this article we point out that the idea of models as a representation of phenomena and the use of models as part of the science practice of modeling can be distinct. The students we worked with had an accurate model of the phenomena, but many did not apply that knowledge to explain their observations with the magnets. These students did not do modeling as a scientific practice.

Why Modeling Matters

The central and important ideas engaged in school science are fundamentally conceptual models. These models span across disciplinary domains in science to include natural selection, Newton’s Laws, the kinetic theory of matter, and so forth. To engage the practice of modeling with students in such content areas, is not to suggest that students need to invent their own model for natural selection, per se. It is to say that students should be engaged in the practice of modeling natural selection. This would mean students would do activities in school where the ideas of the conceptual model of natural selection are used to explain patterns in data.

As we have shown with the simple system of a magnet, despite longstanding familiarity with the ideas of the conceptual model and despite the clarity and accuracy of the data produced by the students, most students struggled to coherently employ the ideas to explain the phenomena. Students seemed to be reasoning with non-modeling approaches.

We believe that the activity presented here may be a productive starting point for building students’ abilities to engage the practice of modeling. Because of the “surprising” orientation of the rectangular magnets’ poles, the activity successfully illustrates where disconnects between ideas about magnets and patterns in magnet data occur. This creates space for teachers to teach, and students to begin to understand how the practice of modeling differs from the “doing school” practice of getting the right answer. We believe that through activities like this along with sustained and continued opportunities to employ conceptual models to account for phenomena in school science experiences—that the visions of science students’ learning found in the NGSS can be realized.

REFERENCES


INTRODUCTION

“When they [sharks] eat people their teeth get sharper.” “They [sharks] have many sets of teeth.” “They [sharks] don’t have bones in their bodies.” “When you see their fin, you don’t know if it is a shark or a dolphin.” “Hammerheads use their heads when they get mad.”

These statements document a conversation with Kindergarten students. The class was completing a K-W-L chart together. This type of chart, common in elementary classrooms, is a K-W-L which is a simple three column chart where the teacher documents what the children Know, What to know, and have Learned through the unit of study. This teaching strategy is used in early elementary classrooms as a way of gaining information from students focused on a specific topic. The kindergarten class mentioned above was interested in exploring oceans and in particular, sharks. The teacher used the children’s interest in this topic to build curricula based on ocean exploration.

The National Science Teachers Association’s (NSTA) position statement on elementary school science clearly states what science should look like in classrooms today. For example, “The elementary science program must provide opportunities for students to develop understandings and skills necessary to function productively as problem-solvers in a scientific and technological world” (NSTA 2002). The position statement goes on to state that elementary students learn science best when “they are involved in first-hand exploration and investigation and inquiry/process skills are nurtured” (NSTA 2002). Additionally, the statement encourages the use of themes in relation to all disciplines of science, mathematics, and communication.
The use of centers in the classroom may help teachers to meet the standards for their state or the Common Core State Standards (CCSS). Although the Common Core State Standards (CCSS) do not yet include the various science disciplines, some literacy and mathematics standards do apply. Targeted CCSS Literacy and Math standards for kindergarten through second grade are addressed in the thematic centers described in this manuscript. Following the description of each center, we have listed some standards that might be met through these introductory centers. Additionally, each year the National Science Teachers Association (NSTA) publishes a list of notable books. In Table 1, several of the titles that address the exploration of oceans with elementary students have been listed.

<table>
<thead>
<tr>
<th>Title</th>
<th>Author</th>
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<tbody>
<tr>
<td>Face to Face With Manatees</td>
<td>Brian Skerry</td>
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<tr>
<td>Pierre the Penguin: A True Story</td>
<td>Jean Marzollo</td>
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<tr>
<td>Project Seahorse</td>
<td>Pamela S. Turner</td>
</tr>
<tr>
<td>Oceans: Dolphins, Sharks, Penguins, and More!</td>
<td>Johnna Rizzo</td>
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<tr>
<td>Face to Face With Penguins</td>
<td>Yva Momatiuk</td>
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<td>John Estcott</td>
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<td>The Fantastic Undersea Life of Jacques Cousteau</td>
<td>Dan Yaccarino</td>
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<tr>
<td>Into the Deep: The Life of Naturalist &amp; Explorer William Beebe</td>
<td>David Sheldon</td>
</tr>
<tr>
<td>Slow Down for Manatees</td>
<td>Jim Arnosky</td>
</tr>
</tbody>
</table>
UNIT OVERVIEW

Often teachers utilize a thematic unit to support cross curricular study. Below, four centers are described that could be used to introduce a thematic unit about oceans. The teacher should first listen to the students to understand their prior knowledge and their questions about the topic. The KWL chart described above is one way to do this. It should be noted that these centers are intended to be introductory to ocean explorations with the intention of more thoroughly investigating each idea to allow for deeper concept development. For instance, a more thorough investigation of sea urchins and angelfish might follow the introductory centers. This investigation may consider color, needs of these creatures as well as the comparison of these living creatures with humans. Additional common core and state level standards may be met through subsequent teaching and student exploration in the unit activities and lessons.

INTRODUCTION TO STUDENTS

“I have been hearing several of you talk about going to the beach, about swimming, and about fishing. Last week, I put out some materials and asked you to use them to represent some of your knowledge about these things, and you can see your representations around the classroom. As a result, I thought we could explore this a bit more. Around here we have shores near lakes and reservoirs, but we are now going to explore the shore and the water found at the ocean.”

“Write your answer to the following on the sticky-it note. Water is the same color as ________________. As a group, we will create a graph on the board with our answers. Let’s look at what our responses may tell us. For instance, many of you said that water is the color of sky, but others of you said that is was the color of your eyes. Does that mean that water can be different colors?”

“Well today, we are going to begin a study of the ocean by visiting four centers. At each center we will explore something that is related to ocean life and our earth. Then later this week, we will explore some of these concepts more in depth.”

GROUPING OF STUDENTS

“Each of you was given a colored card today. If you have turquoise, you will go to center #1 first, if you have tan, you will go to center #2, if you have chartreuse, you will go to center #3, and if you have maize, you will go to center #4 first. When you hear the sound of the ocean, it’s time to move to the next center.” The use of lesser known color words is used to introduce students to variations of colors they may see as they explore the ocean further.
Thematic Centers
Center #1 - Ocean Creatures

A. Materials:
✓ Clay
✓ Toothpicks or paintbrushes for making markings and textures
✓ Related books
✓ Paper
✓ Pen or Pencil

B. Procedure:
- Display real photographs, books (see Table 1), or encourage children to recall their prior knowledge on the ocean creatures. Encourage students to explore one creature from the ocean that they find to be of particular interest. The students then create a representation of the creature using an art medium such as clay. Clay allows students to accurately make markings and create texture by using toothpicks or paintbrushes. Other options of art mediums may include shaving crème and paint. The creatures will be professionally displayed as part of a classroom mural on oceans.
- For example, in the kindergarten class previously mentioned, a student was interested in finding out the length of a great white shark. The student discovered that the average size was 18 ft. In order to make the size more real for the student, the teacher learned that a school bus is approximately 18 ft. long. The class then measured a school bus using side walk chalk to mark the size increments. Later, the class was able to refer back to the sidewalk chalk markings to recreate a great white shark in their classroom.

C. Assessment: The assessment would be an authentic form of assessment. As the students complete their representations of ocean creations, the work could be displayed on a mural.

D. Connection to CCSS – This introductory center may help to meet literacy and math standards about creating texts, the use of drawing, and modeling shapes. Possible connections to CCSS include:

- CCSS.ELA-Literacy.W.K.2 Use a combination of drawing, dictating, and writing to compose informative/explanatory texts in which they name what they are writing about and supply some information about the topic.

- CCSS.ELA-Literacy.SL.K.5 Add drawings or other visual displays to descriptions as desired to provide additional detail.

- Identify basic similarities in and differences between two texts on the same topic (e.g., in illustrations, descriptions, or procedures).

- CCSS.Math.Content.K.MD.A.1 Describe measurable attributes of objects, such as length or weight. Describe several measurable attributes of a single object.

- CCSS.Math.Content.2.MD.A.1 Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.

Center #2 - Seaweed

A. Materials:
✓ Prop box
✓ Ice cream packaging
✓ Jelly (consider placing this is a zip lock bag so the children can feel it.
✓ Vegetables – raw carrots, celery, etc.
✓ Spaghetti noodles – cooked
✓ Chart paper
✓ Paper
✓ Pen or Pencil
✓ Various samples of seaweed – typically available in specialty grocery stores
✓ Internet access
✓ Handout – Is there Kelp in Your Cupboard – one per student (see Figure 1)

B. Procedure:
✓ Have a prop box (a tub, box, or tote) with the following items inside: ice cream packaging, jelly, vegetables, cooked spaghetti noodles. Have students to brainstorm what all of these items have in common,

✓ Create a chart listing their predictions from the brainstorming activity to revisit or for future curricular ideas. Students should also journal about their predictions explaining the connection between the items presented and their prediction using at least five descriptive words.

✓ The answer is that they are all related to seaweed! Visit the Monterey Bay Aquarium website at http://www.montereybayaquarium.org/efc/efc_kelp/kelp_cam.aspx to allow students to see a live kelp cam.

✓ As a follow up activity, explain to the students that seaweeds can be brown, green, or red. Brown seaweed is called kelp, green seaweed is called sea lettuce, and red seaweed is call porphyra (Nicholson 2001). Some seaweeds are chopped and cooked while others are eaten raw (like the raw vegetables you eat) (Wilkes 2001). Seaweed has a texture similar to the cooked spaghetti noodles. It feels slimy. This protects the seaweed from drying out and/or being torn by waves (Wilkes 2001). As described by Wilkes (2001), other types of seaweed that they students could explore include:

- Carrageen – used to make gelatin for jellies
- Dulse – eaten as a vegetable
- Laver – a brown, crinkly sugar kelp served as food

✓ This information could be presented through the use of a Prezi or a PowerPoint presentation so the teacher does not have to remain at this center for an extended amount of time.

✓ Now that the students are interested in seaweed and have some prior knowledge, visit the Monterey bay Aquarium’s website again. An interactive activity is provided and could be used as a home-school connection activity. There is a printable handout asking students, “Is there kelp in your cupboard?”
Is There Kelp in Your Cupboard?

Do you have kelp in your house? Chances are you do! Kelp and other seaweeds are used in a variety of common foods and household items like toothpaste, frozen desserts and salad dressings.

Be a seaweed sleuth and see what food or other products you can find that contain algae! Need help getting started? Read the information below, then look at the ingredients in toothpaste, ice cream and pudding.

Helpful Hints:
Seaweeds are large ocean plants called algae. The three main groups of seaweed are brown, red and green algae, each providing important ingredients for the manufacture of food and other products. Alginate, carrageenan and beta carotene are the names for the algae products you might find in foods or other products in your cupboards. These seaweed derivatives help ingredients mix together and form thick, gooey gels.

Alginites come from brown algae like giant kelp, Macrocystis pyrifera. Alginites help oil and water mix together to form smooth liquids. They are used in a wide variety of foods including desserts, milkshakes, dairy products, canned foods, frozen foods, salad dressings, cake mixes and meringues. Alginites are also used in the manufacture of drugs, cosmetics, building materials, livestock and poultry feed, fertilizers and beer.

Carrageenan is an ingredient found in many kinds of red algae. It’s used to gel foods like ice cream, cosmetics, medicine and other products.

Beta carotene is a natural pigment derived from green algae and other sources. It is used as a yellow-orange food coloring and may prevent certain types of cancers.

© MONTEREY BAY AQUARIUM
http://www.montereybayaquarium.org/lc/activities/kelp_cupboard.asp
Students are asked to go through their cupboards at home and list items containing seaweed. The student could bring this information back to the classroom to share what items they discover contain seaweed.

C. Assessment: A suggested assessment would be the predictions chart containing at least five descriptive words.

D. The activities in this center may help meet standards concerning organizing data and interpreting them. Possible connections to CCSS include:

- CCSS.Math.Content.1.MD.C.4 Organize, represent, and interpret data with up to three categories; ask and answer questions about the total number of data points, how many in each category, and how many more or less are in one category than in another.

- CCSS. ELA-Literacy. Vocabulary Acquisition and Use1.L.6 Use words and phrases acquired through conversations, reading and being read to, and responding to texts, including using frequently occurring conjunctions to signal simple relationships (e.g., I named my hamster Nibblet because she nibbles too much because she likes that).

- CCSS ELA-Literacy, Comprehension and Collaboration 1.SL.1 Participate in collaborative conversations with diverse partners about grade 1 topics and texts with peers and adults in small and larger groups.

- CCSS ELA-Literacy Presentation of Knowledge and Ideas 1.SL.4 Describe people, places, things, and events with relevant details, expressing ideas and feelings clearly.

- CCSS ELA-Literacy Presentation of Knowledge and Ideas 1.SL.5 Add drawings or other visual displays to descriptions when appropriate to clarify ideas, thoughts, and feelings.

CENTER #3 – SAND INVESTIGATION

A. Materials:
- Children’s microscopes
- Paper
- Pencils
- Two small tubs of sand, one dry and one damp
- Small containers of firm plastic
- Various utensils such as metal spoons or flat spatulas

B. Procedure:
- At this center, students will first play and explore the dry sand, then chart words that describe what they see and feel.
- They should then try to pick up a grain of sand and examine it. Afterward, they should draw what they see on one side of the index card. Students should then view the sample already in the microscope and then draw on the other side of the card what they see.
- This will allow them notice differences. If there is extra time, they may explore the damp sand in the other tub.

C. Assessment: Taking into consideration the exploratory nature of this center, there is no assessment.

D. Connection to standards – The activities in this activity may allow teachers to meet standards focusing on observation and comparison. Possible connections to CCSS include:
Center #4 – Water and Friction

A. Materials:
- Two tubs of the following:
  - Glass
  - Plastic, such as bottle caps, water bottles, fruit baskets
  - Plants
  - Shells
- One tub should contain items that have not been in the ocean and the other tub should contain similar types of objects that have been washed ashore.

B. Procedure:
- At this center, students will choose a similar item from each tub and examine it.
- For example, a glass jar from home compared to a piece of glass that has been washed up on the shore (e.g. sea glass).
- They should then fill out a T chart using words to describe each item.

C. Assessment: A Venn diagram comparing the objects – those found in the ocean vs. those that were not could serve as an assessment.

D. Activities in this center may help meet standards concerning comparison, examination, and observation of force, change, and energy. Possible connections to CCSS include:
- CCSS.Math.Content.1.MD.C.4 Organize, represent, and interpret data with up to three categories; ask and answer questions about the total number of data points, how many in each category, and how many more or less are in one category than in another.
- CCSS.ELA-Literacy. Vocabulary Acquisition and Use 2.L.5 Demonstrate understanding of word relationships and nuances in word meanings. Identify real-life connections between words and their use (e.g., describe foods that are spicy or juicy).

As previously mentioned, the centers described above are ideas for initial ocean exploration. Based upon the student’s interest, knowledge, and skill you will want to further develop these areas in subsequent lessons.
Conclusion

Ocean exploration is a vital topic to study with elementary age students. Though a student may not live near an ocean, our teaching experience with young children has shown us that children are very interested in oceans. Following the interest of the students and the nature of the questions they pose, oceans can be explored in elementary classrooms through the use of thematic centers. The thematic centers described above offer K-2 teachers ideas for introducing the topic of oceans while meeting numerous Common Core State Standards. Countless opportunities are available for teachers to integrate the topic of oceans into integrated content areas and hands-on explorations which is considered best practice in science education.

References


**THE THERMITE DEMONSTRATION REVISITED: A DRAMATIC, YET SAFE COMBUSTION**

By Clinton Mikek,* Tom Wakerly, Ben West, Shelby Maurice, Mitch Sable, Andrew Diefenbach, Witold Fuchs, Tim Gornall, and Mark A. Benvenuto,* University of Detroit Mercy, Department of Chemistry & Biochemistry

**INTRODUCTION**

There have been plenty of explosive or combustive reactions that science teachers have used in the past, as means to engage their students in the subject matter in chemistry and in introductory physical science classes. Explosions and combustions can be fun, and can elicit the same physiological responses as riding roller coasters and other thrill rides. Thermite has been used for demonstration purposes to illustrate explosions and combustion, simply because of the impressive nature of the phenomenon.

For the preparation of pure metals pure aluminum is required, but for heating purposes crude aluminum may be employed.¹ Industrially, iron pieces may be welded together using thermite. The joint formed by this welding is claimed to be better than that produced by an electric welder due to the greater uniformity of heat.¹ Thermite railway welding was patented by John H. Deppeler in 1928.² Lonsdale discuses history, process developments and improvements in thermite welding techniques.³ The technique is still used in railroad construction today.³

While the all-or-nothing behavior of thermite limits its military use, it is still utilized by the military in a specialized grenade form. This type of grenade has the ability to burn through weaponry, vehicles, and even thick armor plate.⁴ When a tank or howitzer is disabled, the gun crew is trained to place one thermite grenade in the gun barrel, and a second one on the engine block. By burning a hole through the barrel and engine, the tank or howitzer cannot be used against the gun crew, who, if employing a thermite grenade, are usually in a situation which requires evacuation from the vehicle.

Unfortunately, in recent years, a belief has arisen and seems to have taken hold that thermite is unsafe for demonstrations. This is perhaps due to the fact that the thermite cannot be put out once the combustion starts. However, with a proper understanding of the reaction taking place, and proper safety procedures in place, the thermite reaction can be displayed safely for middle school, high school, or undergraduate students.

**THE COMBUSTION**

The basic chemistry of a thermite combustion is actually quite simple, an oxygen displacement from one metal to another. It can be written:

\[
\text{Fe}_2\text{O}_3(s) + 2 \text{Al}(s) \rightarrow \text{Al}_2\text{O}_3(s) + 2 \text{Fe}(l) + \text{heat}
\]

For introductory physical science classes, and for basic chemistry classes, it represents an easy example of stoichiometry that is not one-to-one for all the reactants and products. The thermite reaction, also known as the Goldschmidt reaction or Goldschmidt process, was reported in 1893 and patented in 1895.¹ Contrary to the belief held by some, while the reaction is very exothermic, it is not explosive. An explosion refers to the increase in pressure in a sealed container. The thermite reaction when used for demonstrations takes place open to the atmosphere, precisely so there is no buildup in pressure. The shower of sparks that accompanies the reaction is often generated.
by where the molten iron ends up or lands – in water or on moist earth, for example.

SAFETY PRECAUTIONS AND PROCEDURE

One of the main reasons for sharing this article with colleagues and friends is that, due to recent demonstrations performed by the authors, it had become evident that a lore has developed around the danger of thermite reactions. Some recent YouTube videos have heightened this concern, as the people performing the experiment do not emphasize safety while demonstrating the reaction. However, the idea that these experiments are unsafe to perform is misinformed and untrue. The authors have found after repeated trials that thermite reactions, when properly executed, can be an informative, fun demonstration that engages the students, and serves to illustrate some solid chemistry.

Reactions are best run outdoors. After any apparatus to hold the thermite is set up (usually clay pots and a stand), any participant involved in the ignition must wear goggles. All personnel not actually igniting the setup must stand away from the ignition site, upwind a safe distance no less than 3 meters away for a small reaction (<2kg) and no less than 6 meters for a large reaction (2 to 5 kg). Remaining in this area is the individual initiating the reaction and a knowledgeable supervising individual. Just prior to ignition the pair identifies the direction the person with the igniter will run after ignition of the thermite and this path is kept clear of people and obstacles. The pair discusses the demonstration step by step prior to running it, no matter how many times either of them has performed it in the past. The supervisor lights the thermite igniter stick with a handheld torch and leaves the ignition site. The remaining individual then places the igniter stick in the powdered thermite and runs/leaves down the exit path. This individual should not turn to watch the reaction until reaching the safe distance.

Note that the stick can just as easily be lit by the same person placing it in the thermite or by the use of a fuse to create a longer time between lighting of the fuse and ignition of the thermite.

The reaction usually burns for only a few seconds. After the reaction has concluded the resultant metal and slag will be very hot. At least one individual must stay at the site until the resulting iron metal has cooled enough to be disposed of.

While the authors tried several variations of the reaction, by altering the setup apparatus, to ensure the maximum safety of all participants and spectators in a demonstration, only one factor at a time was changed over the course of several demonstrations and several weeks. The group started with a one kilogram sample of thermite in a medium sized clay flower pot set on the ground. The thermite was ignited with a thermite igniter stick placed into the flower pot with the speedy retreat down a predetermined path free of obstructions, and is shown in Figure 1. While these reactions can be performed quite safely at the scale of 2 - 5 kg, amounts as small as 100 - 200 grams still are an exciting, highly visual demonstration. Smaller amounts obviously do not produce as much molten iron, but do still provide a clear demonstration of the chemical phenomenon, the redox of iron and aluminum.

The second reaction replicated the first in every detail with the exception of the flower pot being supported by a ring stand apparatus approximately 30 cm above ground level. A cinder block was used as a counterweight to stabilize the ring stand. This allowed people to see the flow of the molten iron.

The third reaction utilized an elevated flower pot of a larger size containing 3 kg of thermite. The igniter stick was improved with the addition of a fuse that was wrapped helically around the stick and taped, with one end protruding toward the handle. This allowed the fuse to be lit with the stick already in place so that larger quantities of thermite
could be ignited with less risk to any individual. The fuse alone was found to be unable to ignite the thermite. This resulted in the practice of using fuse to light the igniter sticks which would then light the thermite.

The fourth reaction used a similar apparatus as the elevated pot. An 8 foot copper pipe was slid over a large ring stand and 4 ring clamps were attached and spaced approximately ½ meter apart along the ring stand. A large flower pot containing 2 ½ kg thermite was placed onto the lowest ring, 1 kg thermite into a medium pot on the next highest ring, and ½ kg thermite in a small pot on the next highest ring. A length of string was tied to a thermite igniter stick and placed through the top ring. The stick was ignited and the string was used to raise and lower the stick into the thermite. This set-up was dubbed the “Thermite Waterfall” by the authors.

The order of the demonstrations was important to ensure the safety of the crew and onlookers. Each reaction changed only one variable, with safety talks about the reaction being performed, the minimum safe distance for onlookers, the egress paths for the individual igniting the thermite, and the possible destruction of parts of the apparatus occurring before each demonstration. The reactions were found to destroy routinely the clay flower pots used to hold the thermite. Later demonstrations with thermite quantities in excess of 5 kg were typically found to destroy the metal supporting apparatus as well. It was also noted that if the ground was wet the reaction caused an eruption of sparks over a large area. The largest demonstration attempted at the time of this writing was 4.3 kg thermite in the Thermite Waterfall configuration.

Perhaps obviously, if a person wishes to attempt this demonstration, start small, and perform at least one trial for yourself and colleagues prior to attempting it in front of a student audience.

ON-LINE VIDEO LINKS
As mentioned, there are several You Tube videos showing thermite combusting, and showing what it can do. Perhaps obviously, some are better produced than others, and some show better safety practices than others. “Thermit Tomorrow” (with this particular spelling) is the name given to the 2012-2013 thermite videos produced at the University of Detroit Mercy. The group performed weekly demonstration on campus from October 2012 through April 2013. Using this name as a search term on youtube.com will show videos that the group has produced with highlights of the year. Notice the position of people and the safety precautions being observed. Also take note of the size of each of the demonstrations. The seventh minute of the video illustrates the thermite waterfall very well.

CONCLUSION
The thermite reaction is a violent, exothermic transfer of oxygen from one metal to another, but this does not automatically make it dangerous and unsuitable as an educational demonstration. Proper safety precautions and supervision make it an experiment that can be shown to, and run by, competent high school and college students. The reaction can be performed quite safely as long as the reaction is sufficiently understood and intelligent safety practices are followed. The lore that this reaction is explosive is untrue, as long as the material is not confined. Common sense safety practices ensure that this reaction can be enjoyed by teachers and students. Flinn Scientific sells pre-mixed thermite in 1 pound containers, and pre-made thermite igniter sticks. Thermite that is sold in two pouches and that must be mixed is routinely sold with directions for mixing, but our group has found that a 1 to 3 ratio by weight of aluminum powder to iron oxide works well.
REFERENCES
Thermit Tomorrow, at: http://www.youtube.com/watch?v=OlZdptXRkDE

Figure 1: A photograph of one kilogram of thermite burning in a clay pot at ground level
SCIENCE FEUD: USING A GAME SHOW MODEL TO UNCOVER STUDENT THINKING IN SCIENCE

By Chiron W. Graves, Assistant Professor of Biology, Eastern Michigan University, Lauren Mayleben, Biology Teaching Major, Eastern Michigan University, Christopher Valasin, Biology Teaching Major, Eastern Michigan University, William Spotts, Site Coordinator, Bright Futures - Ypsilanti Middle School Site

Abstract
Uncovering student thinking is essential to student learning in science (Ritchhart, Church, and Morrison 2011). As science teachers, we need to be able to identify their preconceptions if we want them to learn for understanding but sometimes uncovering their thinking can be a challenge. For our project, we designed a Science Feud game based on the popular game show Family Feud as an alternative to written pre-assessment. We tried out Science Feud in an after-school science club and found that the game was successful in uncovering student thinking and engaging students in the scientific discourse. Team discussions during the game revealed that student thinking about plant growth was influenced more by their prior experiences outside of their science classes then by their science classroom experiences. Additionally, students tended to provide anecdotal rather than scientific evidence as justification for their claims about plant growth. Our initial experience with Science Feud suggests that it can serve as a practical approach to uncovering student thinking in science.

Science Feud: Using a Game Show Model to Uncover Student Thinking in Science

Uncovering student thinking is essential to student learning in science (Ritchhart, Church, and Morrison 2011). A major guiding principle for our current K-12 science education reform efforts is the understanding that students come to science classrooms with preconceptions about how the world works and these preconceptions have a significant impact on student learning (National Research Council 1999; National Research Council 2007). As science teachers, we need to be able to identify their preconceptions if we want them to learn for understanding but sometimes uncovering their thinking can be a challenge. Many teachers typically use written forms of pre-assessment to uncover student thinking, but written assessments can be intimidating to students because they may be viewed as tests. We usually preface administration of written forms of pre-assessment with the statement, “This is not a test so don’t worry about whether you have the right answer or not. I just want to find out what you already know.” However, when we do not ascribe a score to it, they appear to not take it as seriously as we would like. Their responses are generally brief and we may not get an accurate picture of what they already know. In response to this concern about written forms of pre-assessment, our group of secondary science educators investigated alternative ways to uncover middle school student thinking. After multiple brainstorming sessions, we came up with a game show model because of our previous experiences with student engagement. We all recalled playing some type of review game...
at the end of a unit and the level of student engagement it promoted, so we thought the use of a game for our opening club activity would garner similar student engagement. The main goal of our project was to investigate the effectiveness of a game show model in uncovering middle school student thinking in science.

**THE MAKING OF SCIENCE FEUD: HOW WE UNCOVERED STUDENT THINKING ABOUT PLANT GROWTH?**

For our project, we designed a Science Feud game based on the popular game show Family Feud where two families compete against each other by attempting to identify popular responses to surveys conducted on a variety of topics. We selected photosynthesis as the topic for our Science Feud survey because middle school students hold major misconceptions about the role of photosynthesis in plant growth and these misconceptions impede their understanding (Harvard-Smithsonian Center for Astrophysics 1997) making it one of the hardest concepts to teach in middle school (Koba and Tweed 2009). We chose to work with students in an after-school setting because it offered us more freedom and flexibility regarding the topic and facilitation of the game. To assist us in our efforts we turned to the Bright Futures program. Bright Futures consists of after-school programming at multiple sites in four different school districts in Michigan. The focus for the Bright Futures program is on improving academic achievement, developing self-efficacy, and preparing elementary, middle, and high school students for their next levels in schooling (EMU Bright Futures). Each site consists of different after school programming (or clubs) that student participants can sign up for or can be assigned to at the beginning of each academic semester. The Bright Futures site we worked with was at a local middle school.

We had a total of six students in our science club. These six students were selected based on their past social behavior, their expressed interest in science, or both. The club met every Wednesday for about an hour for a period of 5 weeks. Although the main goal of this project was to investigate the effectiveness of our Science Feud game in uncovering student thinking, the club itself was intended to engage students in the scientific practices mentioned in *A Framework for Science Education* (National Research Council 2012). More specifically, we wanted to engage students in scientific discourse and investigations, and we intended to use the student preconceptions identified through Science Feud to help plan our future activities for the club. This provided Chris and Lauren, the two pre-service science teachers on our project team, with an opportunity to practice using student thinking to guide instructional planning while also gaining experience engaging students in scientific practices. For our first club session, participants were split into two teams of three. The two teams competed to identify the most popular responses to questions about plant growth and the role of photosynthesis.

We administered an 8-question, multiple choice survey about plant growth and photosynthesis to all of the Bright Futures participants at the site (about 15 students) during homework time (an independent student work session just prior to our science club meeting). The survey responses were used to generate the Science Feud game using Microsoft PowerPoint as a platform for delivery (figure 1).

Both teams were presented with a survey question and the team quickest to indicate their desire to identify the most popular response was given the first opportunity. Similar to Family Feud, the team was awarded points for identifying a response that made the board (figure 2) and the amount of
Figure 1: Example of a survey question along with the unrevealed responses to the survey and number of individuals selecting that response.

Where do trees get most of the matter that makes up their wood trunks and leaves?

- 
- 
- 
- 
- 
- 

Figure 2: Example of a survey question with revealed responses. In this example, the revealed responses indicate how the competing teams responded to the survey question. The numbers on the right indicate the number of people who had this response on the original survey.

Where do trees get most of the matter that makes up their wood trunks and leaves?

- 
- 
- Carbon Dioxide 3
- Water 1
- Soil 1
points awarded was determined by the ranking of the response. In other words, the most popular response was worth the most points for that survey question. Additionally, if the team selected a response on the board, they were allowed to either attempt to identify another popular response or pass to the opposing team. Science Feud was different from Family Feud in that a team’s response had to be accompanied with a rationale for why they suggested this response. By requiring the teams to provide a rationale for their response, we were able to uncover a deeper level of student thinking that was not uncovered in the surveys. Also unique to Science Feud was a “bonus round” at the end of each survey question.

During the bonus round, the teams were allowed to discuss the question and identify the response they thought was most accurate and why. We used this as a basis to gather further insight into their thinking by listening to their team discussions and the team response they chose to give. It is important to note that although we asked them to identify as a team what they thought the most accurate response was, we did not provide them with “the right answer” as they requested. Instead, we used this as an opportunity to emphasize the nature of science as an investigative process. In order to build excitement for future club activities, we indicated that we would be investigating these questions in future club activities.

**Using Science Feud: Did It Work?**

Science Feud was a hit with the students! All six of the students were very engaged and their competitive nature was evident. They had no problems sharing their ideas and all of the responses they gave were detailed. Most importantly, their engagement in Science Feud provided us with major insight into their thinking about photosynthesis and its role in plant growth. The students were very familiar with the term photosynthesis. They knew that sunlight was involved in the process along with water and carbon dioxide. This was not surprising as most middle school students have been exposed to the term at some point prior to middle school. However, their understanding of the role of photosynthesis in plant growth was still underdeveloped. They did not understand that the majority of a plant’s biomass was generated through the process of photosynthesis and that carbon dioxide was the major source of this biomass. This is similar to the misconceptions identified in previous studies conducted with middle school-aged students (Stavy, Eisen, and Yaakobi 1987). Student engagement in Science Feud also revealed student prior experiences and how they processed these prior experiences. For instance, students indicated that a plant placed in a dark room would still grow because you could never truly prevent light from getting into the room due to the space underneath and on the side of the door. Another interesting and informative response came when one of the students indicated that all organisms, including animals, had the ability to do photosynthesis. The example the student gave to justify this response was that humans need sunlight to synthesize vitamin D hence they do photosynthesis. Clearly, this student used prior knowledge and experiences in forming the justification for the response and Science Feud allowed us to uncover this student’s thinking about the question.

**Conclusion**

Our initial experience using Science Feud suggests that such a model can successfully uncover student thinking in science. They provided us with detailed justifications for their team selections. Their team discussions were very informative as well. When we listened to team discussions we heard how confident students were in their support of an idea. Team discussions also provided us with the origins of these ideas. Most of the students’ ideas resulted from things they heard through television or radio reports or through their personal experiences. They
also attributed some of their ideas to activities or discussions in their science classrooms but they did so less often. This was not surprising since we know students come to our classrooms with preconceptions about how the world works based on their personal experiences and these preconceptions tend to persist if not directly challenged (National Research Council 1999).

Science Feud provided the additional benefit of engaging students in scientific discourse, particularly argumentation. The students were very open and engaged. We attribute this to the non-intimidating nature of the game. Instead of asking students to answer the question, we asked them to work as a team to determine how others answered the question. We believe this eliminated the pressure of getting the “right answer” and the embarrassment associated with “being wrong”. However, we were still able to get at their specific thinking about the question by including an extension round that asked them to identify what response they thought was most accurate and why. Participation in scientific practices and discourse is one of the four strands of science proficiency (National Research Council 2007). A Framework for K-12 Science Education identifies eight scientific practices, one of which is engagement in argumentation from evidence (National Research Council 2012). Science Feud provided us and the students with an opportunity to engage in scientific discourse. More specifically, it provides the students with an opportunity to engage in the practice of argumentation from evidence. Although much of the “evidence” provided by the students was anecdotal, Science Feud as an introductory activity for instruction does provide instructors with a starting point for helping students learn to incorporate the use of scientific evidence to support their argument. Overall, Science Feud set a positive tone for our science club activities, and we believe it can do the same for our science classrooms as well. Our biggest challenge moving forward will be implementing Science Feud in a larger class setting where dividing students into two teams would not be feasible. Perhaps modifying Science Feud to include multiple teams, which we plan to attempt in the fall semester, will address this challenge.

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How to Introduce the NGSS Science and Engineering Practices through Different Learning Modalities
By James T. McDonald and Kristine Stafford, Central Michigan University

Introduction
With the introduction of the Next Generation Science Standards (NGSS), teachers are presented with both an opportunity and a challenge. The opportunity is the chance to bring new instructional strategies to the classroom. The challenge is that the NGSS standards present new material for teachers to think about and implement.

The science and engineering practices contained in the NGSS are a slight change in the way that teachers will think about how science and engineering are done in the K-12 classroom. First of all is the introduction of engineering itself. The National Science Education Standards did not contain standards or practices related to engineering. The inclusion of engineering activities into the classroom will require a transition for all of us. As a science educator, I will have to include these practices in my classroom. As future teachers, my students will have to think about engineering alongside science in a way that is different than the way they learned it. For practicing teachers, it will mean getting used to including engineering activities into already busy instructional schedule.

What are the Practices?
The science and engineering practices introduced in the NGSS (Figure 1) are similar to what we have done in the past in science with some noticeable differences. The Framework for K-12 Science Education (Framework) specifies that the science and engineering practices be combined with disciplinary core ideas as follows:

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
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

The eight science and engineering practices in the Next Generation Science Standards (Appendix, Volume 2, p. 48)

Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content. (NRC, 2012, p. 218)
The Framework specifies that each expectation that we have for a student combine a relevant practice of science or engineering, with a core disciplinary idea and crosscutting concept, appropriate for students of the specified grade level. That guideline is the most significant way in which the NGSS differs from previous science standards. Students will not be assessed on how they understand the core ideas and their abilities to use the practices of science and engineering. These will now be assessed together, showing that they know science concepts but how they can use their understanding to investigate their world through the practices of science inquiry.

The Framework uses the terms practices rather than “process skills” or “inquiry skills” for a specific reason:

We use the terms “practices” instead of a term such as “skills” to emphasize that engaging in scientific investigation requires not only skill, but also knowledge that is specific to each practice. (NRC, 2012, p. 30)

The development of the standards provides insights into the science and engineering practices. Those insights are conveyed through the following guiding principles:

- Students in grades K-12 should engage in all eight practices over each grade band.
- Practices grow in complexity and sophistication across the grades.
- Each practice may reflect science or engineering.
- Practices represent what students are expected to do and are not teaching methods or curriculum.
- The eight practices are not separate; they intentionally overlap and interconnect.
- Performance expectations focus on some but not all capabilities associated with a practice.
- Engagement in practices is language intensive and requires students to participate in classroom science discourse.

**Different Learning Modalities**

It is this last guiding principle that we would like to concentrate on for the remainder of this article. Helping and assisting students to become familiar with the language of science and engineering is another challenge. So how can we help and assist students become familiar with the language of science and engineering.

One instructional strategy that has been suggested by the Seeds of Science, Roots of Reading (Seeds) program developed at the Lawrence Hall of Science at the University of California, Berkeley suggests that students need to:

- Do It
- Talk It
- Read It
- Write It

The guiding principle of this program is that we need to engage students through multiple learning modalities. This includes the development of scientific discourse and academic vocabulary by combining science/engineering with literacy. This can be seen through describing each of the four parts of the approach used in Seeds using the sequence used in the unit Shoreline Science:
Do It. Students observe sand samples.

Do and Write. Students make observations of one kind of sand and record observations by completing a “sand journal”.

Talk and Read. Students form expert groups who studied the same kind of sand to focus on the question of “How was this sand formed?” Expert groups compare their sand journals and discuss evidence. Students use the language of argumentation such as “Why do you think that,” “I think this because...” and “How do you know? What is your evidence?” Students refer back to the nonfiction reader Gary’s Sand Journal to get more evidence.

Write. Expert groups record observations and inferences, students write a scaffolded explanation, and later students revisit and write a more independent explanation. (Barber, 2010)

The Seeds program uses nonfiction readers that come with the curriculum. Another way to have students engage in scientific discourse and academic language related to engineering is to read children’s literature that reflects the practices of engineering to your class. In the list that appears at the end of the article are some suggested books that we have found present different important elements of engineering including sports engineering, women in engineering, sound engineering, civil engineering, the development of machines, the career of an engineer.

If you read the book to your class as the beginning point to an investigation, it engages children in the language of the investigation; they can share their prior knowledge of engineering and listen to one another’s thoughts. Students can record their thoughts in a science journal and then discuss it using a think, pair, and share model.

The students in your class may not have thought very much about engineering but it is all around them. Introducing them to the language and concepts of engineering through children’s literature and combining it with active engineering investigations can help them use many of the science and engineering practices. Integrating science and literacy will allow for more time for the teaching of science. The language of science cannot be separated from reading. They naturally go together.

References

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Engineering Children’s Books

High Tech Hot Shots: Careers in Sports Engineering Paperback
By Celeste Baine
The National Society of Professional Engineers, 2004
Grades: 7-12
This book provides students with ways to combine a passion for athletics with an interest in engineering. This book compiles information, resources, and stories of engineers in the sports industry that design new and improved products for both athletes and spectators.

Changing Our World: True Stories of Women Engineers
By Sybil E. Hatch
American Society of Civil Engineers, 2006
Grades: 3-6
Explore the lives and careers of hundreds of women engineers of all ages and backgrounds. These colorful stories describe extraordinary women who serve as role models in the world of engineering.

Engineering Elephants
by Ph.D Emily M. Hunt and Ph.D Michelle L. Pantoya (consultant)
AuthorHouse, 2010
Grades: Preschool-3
Engineering Elephants introduces the engineering profession and fundamental science and engineering concepts. The story chronicles the journey of an elephant that is questioning the world around him. Science and math concepts such as velocity, momentum, and problem solving are explored in this book.

Cool Science Careers: Sound Engineer
By Patricia Hynes
Gareth Stevens Publishing, 2007
Grades: 4-8
This book explores the work of sound engineers in movies, sports, television, and music. Through engaging sidebars and callout text, readers develop a better understanding of sound engineering and the skills needed for this job. This book is part of the Cool Science Careers series; other titles related to engineering include Bioengineer and Robot Scientist.

Engineering the City: How Infrastructure Works, Projects and Principles for Beginners
By Matthys Levy and Richard Panchyk
Chicago Review Press, 2000
Grades: 4-8
Engineering the City tells the fascinating story of infrastructure as it developed through history along with the growth of cities. The visible and hidden elements of a city are described in detail. Experiments, games, and construction diagrams show how these structures are built, how they work, and how they affect the environment of the city and the land outside it.
The New Way Things Work
By David Macaulay
Houghton Mifflin Harcourt, 1998
Grades: 4-7
Text and images describe twelve new machines and provides details about the latest innovations. From watches to cars, this book describes the scientific principles behind well-known technology. There is even a section about the world of digital machinery.

I Want to Be an Engineer
By Stephanie Maze
Houghton Mifflin Harcourt Books for Young Readers, 1997
Grades: 3-6
This book explores various engineering careers, such as civil, mechanical, and electrical engineering. It also includes details about the education, qualities, and skills needed to become an engineer, as well as some of the professional and educational organizations related to the field.

Engineering the ABC's: How Engineers Shape Our World
By Patty O'Brien Novak, illustrated by Don McLean
Ferne Press, 2009
Grades: Preschool - 2
This book answers questions about how everyday things operate, such as airplanes and bicycles. Each letter of the alphabet represents a different object created by engineers. The book also makes connections between engineering and a child's daily life, showing children how engineers shape our world.

Engineering Feats & Failures (Time for Kids series)
By Stephanie Paris
Teacher Created Materials, 2012
Grades: 3-6
This book begins by describing some of the first great feats in engineering, such as the Great Pyramid of Giza, the Great Wall of China, and Stonehenge. Successes from the Industrial Age, such as the Panama Canal are discussed, as well as some of the failures, including the Titanic. This colorful and detailed book ends its presentation discussing current engineering feats, such as space travel and the man-made islands off Dubai.

Rocks, Jeans, and Busy Machines: An Engineering Kids Storybook
By Alane Rivera and Raymundo Rivera
Rivera Engineering, 2010
Grades: K-2
This book is written by professional engineers. Pedro and Violet encounter engineering when walking by a construction site. Violet teaches Pedro about concrete and the way engineers use it. Pedro also learns how engineers are responsible for designing buildings and bridges that are strong and safe for people to use.
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Central Michigan University’s Research Experience for Teachers: The Importance of Failure as Part of the Engineering Process
By Michelle Vanhala, Education and Human Services Science/Mathematics/Technology Center, Central Michigan University

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Abstract
Central Michigan University’s Research Experience for Teachers is a program funded by the National Science Foundation to provide current and future science teachers the opportunity to participate in research and professional development opportunities. As the teachers came to learn over the course of the program, making mistakes and even failing is a normal part of the engineering process. Using a survey to assess perceptions both quantitatively and qualitatively, this study sought to address the role of failure in the engineering process by analyzing the mistakes that occurred and the lessons that followed for the teachers throughout their research experience. Results confirmed the significance of failure as a part of the engineering and even learning process, and implications for classroom instruction are discussed.

Introduction
“Take chances, make mistakes, and geeeet messy!” was the catchphrase of the popular children’s book and television character Ms. Frizzle, an unconventional science teacher who was notorious for embarking on fantastic field trips with her students and their magic school bus (Scholastic, 2013). As a child, I idolized Ms. Frizzle, and when it came to science experiments (or anything involving learning, really), I enthusiastically took her advice as an excuse to dive right into a project.

Today, as I am wrapping up my educational theory and science pedagogy classes in preparation for my own classroom of young scientists, I can’t help but reflect on that old, familiar maxim from my childhood. I wonder - how often do we as teachers really give students the opportunity to take chances, make mistakes, or get messy? When in our meticulously designed lesson plans are students allowed to take command of their education and learn from their own failures? In this paper, I reflect upon one of the key lessons learned during my National Science Foundation Research Experience for Teachers experience: the significance of failure as part of the engineering and learning process.

Engineering and the Next Generation Science Standards
The engineering design process involves a series of steps that ultimately lead to the
creation of an innovative device: identification of the problem, criteria, and constraints, brainstorming solutions, generating ideas, exploring possibilities, selecting an approach, building a model, and refining the design (NASA, 2008). The process is summarized in Figure 1, a flow chart obtained from RET NSF Project at CMU (2013): 

Figure 1. The Engineering Process. This figure illustrates the engineering process (RET NSF Project at CMU, 2013).

The New Generation Science Standards (NGSS) are standards for K - 12 education that seek to specifically incorporate the engineering design process as described above. According to the NGSS website (2013), the standards’ framework “rests on a view of science as both a body of knowledge and an evidence-based, model and theory building enterprise that continually extends, refines, and revises knowledge.” This framework is comprised of three dimensions: practice, which provides students with opportunities to engage in scientific inquiry and engineering; crosscutting concepts, which emphasize applications and recurring themes across the field of science and even other disciplines; and disciplinary core ideas, which are broad learning objectives that fall under the categories physical sciences; life sciences; earth and space sciences; or engineering, technology, and applications of science (NGSS, 2013).

Central Michigan University’s Research Experience for Teachers
Central Michigan University’s Research Experience for Teachers (RET) is a six-week summer program funded by the National Science Foundation designed to provide current and future high school science teachers the opportunity to participate in research alongside engineering faculty and students. Research topics included analysis of Dicthystelium movements, refinement of a fall detection phone application, circuit board development, medication delivery simulation using a computer program, and robotic operations. In addition to hands-on engineering research projects, teachers also participated in a wide range of professional development activities, including technology training, lesson designing and implementation using NGSS, and conversations regarding current issues in education. After the six-week program was completed, pre-service teachers had the opportunity to travel to the classrooms
of in-service teachers to implement interactive lessons that required students to apply the engineering process. RET teachers also were challenged to apply the lessons learned from the program into their subject matter curriculum design in order to ultimately benefit their students. According to one study, the students of teachers who were involved in a research program such as RET for at least three years passed a standardized science test at a rate that was 10% higher than students of non-participating teachers (Silverstein, Dubner, Miller, Glied, & Loike, 2009).

Literature Review
In addition to my own observations regarding the significance of failure during my RET experience, additional research confirms its importance. In a study by Slegers et al. (2011), a panel of engineers was interviewed regarding their experiences with and perceptions of failure. Initial impressions of the interviewees included shock at the panel’s subject: in the words of one participant, “People don’t talk about failure; they talk about how to avoid failure” (Slegers et al., 2011, p. 3). In contrast, however, themes that emerged from the engineers’ interview responses included the importance of having an attitude that was open to failure and the significance of failure as part of the reassessment stage of the engineering process. Similarly, Livio (2013) analyzed the failures of five famous scientists including Charles Darwin and Albert Einstein whose works ultimately “changed our understanding of life and the universe,” “despite and because of their errors” (p. 1). From these scientist’s stories, Livio (2013) concluded that “the scientific process advances through error. Mistakes are essential to progress” (p. 1). Likewise, Petroski’s (1985, 1994, 2007) analyses of real-life engineering failures such as the sinking of the Titanic and the loss of the space shuttles Challenger and Columbia illustrated the lessons that led to future success, highlighting the role of failure in design revision and engineering judgment.

In regards to learning in general, a research study conducted by Kornell, Hays, and Bjork (2009) demonstrated that students actually performed better on challenging tests after being asked to come up with wild guesses to answer questions related to the material. It seems that, rather than studying and avoiding errors, students learned better if they were given the opportunity to try and fail. These studies in conjunction with many other articles (Sponder, 1993; Saunderson, 2012; Richardson, 2012; Hunt & Rose, 2012) provide the foundations for additional research that examines the learning opportunities that may arise from failure.

Methodology
In order to assess the role of failure in the engineering process during the course of the six-week summer RET program, surveys that incorporated both quantitative and qualitative questions were sent out to a total of seven engineering undergraduate student participants, eight current high school science teacher participants, and four undergraduate pre-service science teachers. The survey questions are included below in Appendix A. (Questions marked with an asterisk were required to be completed; those without were optional.)

A total of 13 responses out of 18 elicited were received. Responses were automatically and anonymously accumulated in a Google Drive Forms spreadsheet. Quantifiable responses are summarized in the results section below, and qualitative responses were coded using a constant comparative method grounded in Strauss’ (1987) approach.

Although the data obtained was valuable, limitations that must be acknowledged include a small sample whose relatively extensive engineering and/or RET experience may skew
results, questions that could be considered “leading,” and the subjectivity of qualitative data. Regardless of these limitations, the responses received were nevertheless significant.

Results
Survey results revealed that all participants experienced some sort of failure at least once every other week, with eight responding that they experienced failure “once every few days” or “once a day.” (See Figure 2 below.)

Figure 2. Failure Frequencies. This figure illustrates the responses of participants to survey question one.

All participants expressed that failure results in a learning opportunity at least “sometimes,” with five responding that it “often” did and another five responding that it “always” did. (See Figure 3.)

On average, from a scale of one to five (one being the least important and five being the most), participants quantified the importance of failing/making mistakes during the engineering process as a 4.2 and the importance of failing/making mistakes during the learning process as a 3.8.
Figure 3. Learning opportunities from failure. This figure illustrates the responses of participants to survey question:

<table>
<thead>
<tr>
<th>Response</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Always</td>
<td>3</td>
</tr>
<tr>
<td>Often</td>
<td>5</td>
</tr>
<tr>
<td>Sometimes</td>
<td>2</td>
</tr>
<tr>
<td>Rarely</td>
<td>1</td>
</tr>
<tr>
<td>Never</td>
<td>0</td>
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From analysis of the open ended questions, several recurring themes emerged and are summarized in Table 1 below.

<table>
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### In a few sentences, describe a time in your research when you experienced failure.
- Nearly all participants explained a situation in which their device/algorith/simulation was not working as it was expected.

### In a few sentences, describe what you learned from your failure, if anything.
- Participants learned what not to do in the future.
- The issue was broken down into smaller, more manageable parts.
- Participants researched relevant theories or asked for advice from another to solve the issue.
- The design/procedure was ultimately modified to fix the issue.
- Multiple new design directions were discovered.
- Participants learned life skills such as patience, persistence, and appreciation of successes.

### Briefly describe why you responded as you did. (On a scale of 1 to 5 (1 being the least important and 5 being the most important), how would you rate failing and making mistakes as part of the engineering process?)
- Failure allowed participants to learn why something wasn’t working and learn more about a theory or device by deepening understanding of it.
- An even better, more successful device was created as a result of the initial failure.
- The participants learned life lessons such as humility, acceptance, and perseverance from their failures.

### Briefly describe why you responded as you did. (On a scale of 1 to 5 (1 being the least important and 5 being the most important), how would you rate failing and making mistakes as part of the learning process?)
- Students learn better from mistakes.
- Failing and making mistakes teaches life lessons that prepare students for real life.
- The teacher had to be secure enough to fail in front of their students.
- There needs to be a balance between challenge and achievability in the classroom.

Table 1
Across both the quantitative and qualitative responses, participants indicated that they learned important lessons related both to their engineering projects and to life in general from their mistakes, and all indicated their support for providing carefully designed opportunities for failure in the classroom as well.

Discussion
Overall, the data collected demonstrated the significance of failure as a part of both the engineering and learning processes, confirming the results of Slegers et al. (2011), Livio (2013), and Petroski (1985, 1994, 2007). In the words of one respondent, failure is “necessary” for true engineering to take place. Often, the opportunity to learn from failure increased participants’ understanding of concepts and devices. As one said, “When we fail,
we find out more than if we succeed because we know more than only what works... We know why it will work when we redesign something the next time.” Another explained, “We learned that science should not end at failure. It should really begin there.” Petroski (2007), who has written extensively on the role of failure in the engineering process, echoed the participants’ sentiments: “Engineers often look to examples of success and failure to guide their designs. Paradoxically, it is the failures that are the more reliable teachers.”

Interestingly, the survey participants also demonstrated support for the idea that failure provided important life lessons beyond simply engineering and science concepts: the opportunity to make mistakes taught humility, perseverance, problem-solving, and the value of risk-taking. Ultimately, as one respondent asserted, “students who are willing to take risks and problem-solve are more prepared to enter real life after high school.”

Regarding classroom learning, responses indicated that students who are given the opportunity to fail and then learn from their failure have the potential to learn even more effectively. According to one RET teacher, the bottom line is that, simply, “students don’t learn if they never have to struggle,” an assertion that supports the findings of Kornell, Hays, and Bjork (2009) as well as additional sources that have affirmed the correlation between challenge and student achievement. For example, in a study of high school science students in Portugal, Fonseca and Conboy (2006) demonstrated that teachers’ high academic expectations contributed to student’s success in science and concluded that “the ultimate goal should be the development of a culture of high expectations within a supportive environment” (p. 91). Moreover, according to Arum and Roksa (2011), a lack of academic rigor is a widespread contributor to the under-preparedness of college students. Although their particular study is specific to institutions of higher education, it could be surmised that the academic idleness Arum and Roksa (2011) described originates before the undergraduate years. In order for students to develop the skills that are crucial for success in college and throughout life, Arum and Roksa (2011) suggested that schools focus on increasing rigor, a conclusion that this data regarding the learning opportunities that arise from struggle and failure would uphold.

Several survey responses did caution that there needs to be a careful balance between achievability and challenge, as students may take longer to learn from their mistakes and may get frustrated and even give up when faced with failure. Sanford (1962) likewise asserted the necessity of this balance in his student development theory, which confirmed
that all students will experience failure or negative consequences in life that they can ultimately grow and learn from with the right supports. Echoing the concerns articulated by respondents, Kohn (2012) advised that an environment must be carefully structured in order to preclude students from giving up after experiencing failure. In Kohn’s (2012) words, “challenge - - which carries with it a risk of failure - - is part of learning,” but in order to learn, those challenges need to be “engaging” and “relevant” to persuade students to persist even after failure, students need to have a choice in the curriculum and content, and an emphasis needs to be placed upon the process rather than the results. Jerome Bruner is quoted to illustrate this final concept, that success and failure should be experienced by students “not as reward and punishment but as information” (Kohn, 2012). It is the teachers’ responsibility to create a learning environment in which students are encouraged to use their failures as directives for future actions.

In order to develop students’ perceptions of failure, time for reflection must be scheduled into lessons. As an illustration of this, the survey itself prompted RET members to reflect upon their learning experiences by structuring questions in such a way as to encourage participants to highlight how instances of failure enabled them to move forward in their research in new ways. Raths et al. (1966) characterized reflection as one of the most importance practices of students developing critical thinking skills, and McGuinness (1993) likewise emphasized the importance of metacognition as an exercise to “make the students’ thought processes more explicit” (p. 311) Several techniques that teachers can employ to promote reflection include asking students for examples, similarities, assumptions, and inconsistencies/alternatives while challenging them to question prior assumptions, use broad classifications, and evaluate data (Raths et al., 1966). McGuinness (1993) also suggested that teachers model reflective thinking techniques, scaffold students’ attempts, and encourage reflection regarding the strengths and weaknesses of a thinking process along the way. Employing these techniques during and after instances of failure may help students make sense of their own thinking processes in order to better learn from them.

Although not specifically mentioned in the surveys, it is important to remember that teachers’ lessons may fail too, and just as students can be directed to justify their failures in terms of learning, teachers also can benefit from reflection and revision after a lesson goes poorly. In a case study of a failed mathematics lesson, for example, Handa (2008) was sure to emphasize that, with careful reflection, “a so-called ‘failed’ lesson, in fact, has the potential to becoming a meaningful success toward professional growth” (p. 123). The survey’s responses and Handa’s (2008) study are important reminders of the value of failure for future and current teachers alike.

A final interesting note that was included by one participant as an extra comment was the significance of the RET program for the teachers. As the respondent explained, “The RET program was perfect for providing an experience so that I can relate back to my students.” It seems that by giving teachers the opportunity to experiment, occasionally fail, and then learn from those failures, at least one teacher was reminded of what it felt like to be a student, ultimately strengthening teaching techniques. As Waldron (2006) reported after spending a year as a student in another teacher’s classroom, the opportunity to be a student again “provided a dose of reality that strengthened [her] teaching practice.” Her time as a student helped her perceive practical teaching techniques to help her own students learn. Teachers need to embrace opportunities to grow and learn, and one way to do that seems to be by sitting in the student’s seat.
Conclusion

After my experience in the National Science Foundation’s RET program, my personal commitment to providing a hands-on, inquiry- and engineering-driven science education for my future students has been reinvigorated. Fortunately, it seems as if the field of science education as a whole is also moving towards an inquiry- and engineering-based methodology with the implementation of the NGSS (NGSS, 2013; National Research Council, 2010; Harkema, Jadrich, & Bruxvoort, 2009). As this research and others confirm, making mistakes and even failing are important parts of the engineering and learning processes. Such an educational approach falls in line with Freire’s (1970) pedagogy, which theorizes a humanist philosophy in which the ideal partnership between a teacher and a student is characterized by ongoing communication, inquiry, creativity, invention, critical thinking, challenge, and reflection. In the words of Freire (1970), “Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world, and with each other” (p. 72). Freire’s (1970) liberating, dialogical pedagogy has the potential to cultivate autonomous thinking, “committed involvement,” and the ability to perceive the connections within the world between peoples and ideas (p. 69). Providing our students with genuine learning opportunities with these goals in mind enables them to grow as scientists and engineers as they are allowed to take chances, make and learn from mistakes, and maybe even get a little messy along the way.

References


Appendix A

1. Across the course of this six week summer program, roughly how often would you say you encountered an engineering failure or mistake that caused you to become temporarily “stuck” in the research process? *
   ○ Once every five to six weeks (or less)
   ○ Once every three to four weeks
   ○ Once every other week
   ○ Once a week
   ○ Once every few days
   ○ Once a day
   ○ More than once a day

2. In a few sentences, describe a time in your research when you experienced failure. *
   What were you working on? What happened? What was the problem? What was your reaction? How did you proceed?

3. In a few sentences, describe what you learned from your failure, if anything.*
   How did it help your engineering process or design overall, if at all?

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4. How often would you say failing or making a mistake results in a learning opportunity for you? *
   ○ Never
   ○ Rarely
   ○ Sometimes
   ○ Often
   ○ Always

5. On a scale of 1 to 5 (1 being the least important and 5 being the most important), how important would you rate failing and making mistakes as part of the engineering process?*
   ○ 1
   ○ 2
   ○ 3
   ○ 4
   ○ 5

6. Briefly describe why you responded as you did. *

7. On a scale of 1 to 5 (1 being the least important and 5 being the most important), how important would you rate failing and making mistakes as part of the learning process in the classroom? *
   ○ 1
   ○ 2
   ○ 3
   ○ 4
   ○ 5

8. Briefly describe why you responded as you did. *

9. Anything else to say about the importance of failing/making mistakes as part of the engineering/learning process?
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