INNOVATIVE COMPOSITE RESEARCH MODELED IN THE MIDDLE SCHOOL CLASSROOM

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Finding means by which teachers may effectively convey science, technology, engineering, and math (STEM) principles to middle school students is often difficult. *A Framework for K–12 Science Education* (NRC 2012) suggests "the actual doing of science or engineering can pique students' interest, and motivate their continued study." It is also important when developing STEM practices for middle school students to anchor the concepts in real-world situations in order for students to make tangible connections. In addition, the *Framework* states that "engaging in engineering practice helps students form an understanding of the work of engineers as well as the links between engineering and science" (NRC 2012). With this in mind, two middle school teachers collaborated with a University of Maine professor to develop a unique means for students to explore how composites (mixtures) can be designed to create materials with more desirable properties. Working in conjunction with the Forest Bioproducts Research Institute, the authors developed an inquiry-based middle school investigation. This activity can be used to emphasize the importance of trees as a natural resource in addition to utilizing engineering practices. Since trees and wood products are ubiquitous and touch everyone's lives in forms like paper, cardboard, plywood, and lumber, students everywhere will be able to relate to the importance of wood and wood products.

This middle school exploration is rooted in the innovative composite research being conducted at the University of Maine. The university is performing extensive research into materials produced by combining polymer resins with wood, fabric, concrete, ceramics, and other materials in the quest to produce stronger, more durable composites. Such composite materials have been found to be extremely useful in marine, automotive, and construction applications, to name a few. Composite-materials research is an extremely viable field of engineering, which can be easily modeled in the middle school classroom with simple ingredients such as flour, water, salt, and sawdust.

This lesson provides a model for teachers to use trees as a natural resource, but if desired, an alternative local natural resource could be substituted for the sawdust. Other possible strengthening materials include ground corn husks, cotton strands, ground coconut husks, or other plant materials.

Several connections to middle school physical science and engineering practices, core ideas, and crosscutting concepts from the *Next Generation Science Standards* (Achieve Inc. 2013) are demonstrated throughout the activity, along with several English language arts (ELA)/literacy and mathematical *Common Core State Standards* (NGAC and CCSSO 2013).

The objective for this investigation is for students to develop a stronger composite plank made from bakers dough and sawdust. One targeted standard of this activity is properties of matter (MS-PS1-3. Gather and make sense of information to describe that synthetic materials come from natural resources and impact society) (Achieve Inc. 2013). Students attempt to manipulate the properties of dough-based planks by developing composites of dough infused with sawdust. This activity also explores forces and interactions (MS-PS2-2. Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object) (Achieve Inc. 2013). The idea of determining the maximum amount of force (stress) a particular plank can handle before breaking, in the form of weight hanging from the middle of the plank, is also employed (Engineering design: MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, and MS-ETS1-4) (Achieve Inc. 2013). This experiment simulates what research engineers do when challenged to develop materials that possess superior properties at a reasonable expense.

As already mentioned, this laboratory experience was developed with the National Research Council's *Framework for K–12 Science Education* (2012) and the *Next Generation Science Standards* (Achieve Inc. 2013) in mind, but mathematics is also heavily embedded in the wood-composite investigation and hits the following Common Core State Standards for mathematics: MP.2, reasoning abstractly and quantitatively; MP.4, model with mathematics; 6.RP.A.3, use ratio reasoning to solve real-world and mathematical problems; and 7.EE.B.4, use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about quantities. Several *Common Core State Standards* for English language arts are also met: RST.6-8.1, cite specific textual evidence to support analysis of science and technical texts; RST.6-8.7, integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually; and RST.6-8.9, compare and contrast the information gained from experiments (NGAC and CCSSO 2010).

This composite investigation is a robust laboratory experience, and it is recommended to conduct the research project either midway through or toward the end of the school year, as it incorporates several common physical-science content topics, including understanding how to design a scientific experiment, physical and chemical changes and properties, and the concept of forces.

FIGURE 1 **Wood-composite pretest** (correct responses are in bold)

1. Composite materials are engineered materials comprising two or more substances with significantly different physical properties. There is a matrix, which provides structure (holds everything together), and a reinforcement, which is used to strengthen the composite. In ancient times, brick composites were made from straw and mud. Which substance was the matrix and which the reinforcement?
   - a. **Mud is the matrix, and straw is the reinforcement.**
   - b. Straw is the matrix, and mud is the reinforcement.
   - c. The mud acts as both matrix and reinforcement.
   - d. The straw acts as both the matrix and reinforcement.
   - e. I do not know.

2. Which data would you use as evidence that a composite plank is the strongest and most efficient?
   - a. The total mass of the plank
   - b. The total mass held by the plank
   - c. The density of the plank
   - d. **The ratio of the total mass held by the plank over the total mass of the plank**
   - e. I do not know.

3. In this research experiment, you will compare the strength of wood-composite planks to the ratio of sawdust to flour in each plank. Which of these two variables is the dependent variable (responding variable)?
   - a. **The strength of the planks**
   - b. The ratio of sawdust to flour
   - c. Both variables are dependent (responding) variables.
   - d. Both variables are independent (manipulated) variables.
   - e. I do not know.

4. When mixing together the sawdust and the flour for your plank composites, it is
   - a. **important to try to get the plank as homogeneous as possible, although it will never be truly homogeneous.**
   - b. important to try to get the plank as heterogeneous as possible, although it will never be truly heterogeneous.
   - c. not important to mix the ingredients well.
   - d. I do not know.

5. If your wood-composite plank breaks after adding more than 2 kg of mass to it, the maximum weight or stress (force) the plank could handle is approximately

   a. 2 Newtons

   b. 20 Newtons.

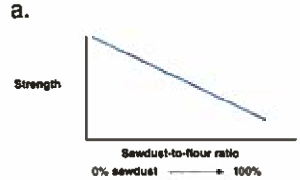
   c. 200 Newtons.

   d. 2,000 Newtons.

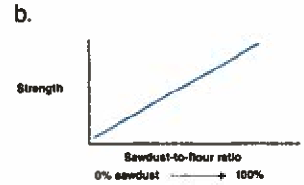
   e. I do not know.

6. Predict which of the graphs below would best describe the results of testing all the different ratios of sawdust to flour for the plank composites.

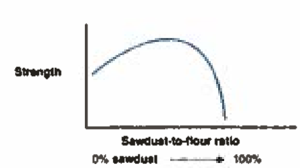
a.



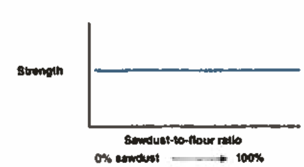
b.



c.



d.



Days 1 and 2: Introduction

This hands-on, minds-on lab inquiry in which students develop the strongest-possible composite using only flour, salt, water, and sawdust will easily capture students' attention and is a good model for materials-science research. Teachers need to explain to students that a composite is a material made up of two or more materials that are combined in a way that allows the combined materials to be stronger and more durable than each of the individual materials alone. Before jumping into the cutting-edge research being done in materials science, teachers can highlight composites found in nature by showing a time-lapse video of barn swallows building a nest of twigs and mud (see Resources). A long time ago, people used this same technique to create primitive brick; the Egyptian practice of using straw in making bricks is even mentioned in the Bible (Lucas and Harris 1962). The straw acted as the fiber, or reinforcement, and the mud was the matrix that held the bricks together. By combining these two materials into a composite, ancient civilizations developed a better and stronger building material (Spencer 1979). There are also many examples of synthetic composites derived from natural resources that are currently used in our society, such as dental composites for filling cavities and wood/plastic composites for decking and outdoor furniture (see Resources for more composite-research examples).

A wood-composite formative assessment in the form of a pretest (Figure 1) helps teachers assess students' readiness to tackle some of the dominant concepts embedded within this research project. A review of one or more concepts might be necessary if the instructor believes a class is not prepared to proceed with the composite investigation. Teachers can also prepare a few sample dough planks (see "Straight Bakers Dough" recipe in Figure 2) and demonstrate the strength of the planks by hanging weights from them until the planks break. Next, students observe under a microscope a wet mount of a few filaments of sawdust and sketch and record their observations on the Activity Worksheet.

Working in groups of three to five, students should then develop a hypothesis regarding why adding sawdust to the dough plank may help create a stronger composite and what they think would be the optimum ratio of sawdust to flour (too much reinforcement without enough matrix and the plank will crumble; too much matrix without enough reinforcement and the plank strength does not improve). The challenge for students is to modify the properties of a dough plank to make it stronger (i.e., hold more weight) by only substituting a percentage of flour with sawdust in the plank recipe.

While an Activity Worksheet is included here, students could also decide as a class how to approach this challenge through engaging in argument from evidence based on experimental designs. The class may decide to assign a specific recipe to each group (group 1: 100% flour; group 2: 25% sawdust, 75% flour; group 3: 40% sawdust, 60% flour; etc.; see sample recipes in Figure 2). Students may decide to have each group form and test four planks (which is the procedure outlined in this paper), or they might want to have each group create enough planks so that they can provide one plank to each group (six groups, six planks) for testing. Once each group tests its planks, the raw data are averaged,

FIGURE 2 Example plank recipes

	Straight bakers dough (mL)	25/75 sawdust to flour (mL)	40/60 sawdust to flour (mL)	50/50 sawdust to flour (mL)	60/40 sawdust to flour (mL)	75/25 sawdust to flour (mL)
Flour	200	150	120	100	80	50
Sawdust	0	50	80	100	120	150
NaCl	50	50	50	50	50	50
H_2O	80	80	80	80	80	80

Note: Although measing by mass is more accurate, the densities of ????? can vary significantly between tree species. Using volume instead of mass is a means to standarize the composite recipe. See references for more information about density.

and the averages for each plank recipe are pooled with the entire class. A class may also decide to have each group make and test several different set recipes, although this approach will require more time. Student groups would then pool their data with the class as individual trials. There are pros and cons for any of these approaches, which should be discussed, but as is the case for scientific research engineers and scientists, designing an experiment is often done within parameters that may or may not be ideal. Any experimental-design deficiencies brought up by students should be recorded on their Activity Worksheet and addressed in the conclusion of the laboratory report. The class should discuss the following topics:

- Variables/control—The strength of the planks is compared to the planks that are made up of 100% flour.
- Reproducibility—Every step of the experiment needs to be recorded so that anyone can reproduce the experiment and get the same results.
- Replication—It is important to test more than one plank.
- Data integrity—It is necessary to develop a standardized method to follow and make sure there are no deviations or shortcuts.
- Averaging and sharing data—The entire class must average trials and pool data to draw a conclusion.

Students also need to develop and agree on a standard method of testing each plank and how they will quantify their results. Testing the strength of the planks could be a lesson in scientific discussion/proposal presentation in which student teams suggest a method that they believe would work, draw up a plan or proposal, and present their idea to the other design teams. Students would then vote on which class method for testing the planks would be most appropriate (MS-PS2-4). The method for testing the planks provided in this paper should be modified to incorporate the ideas of each class. Also, students should brainstorm about the type of data that should be collected, which may affect the results of the experiment. For example, students may want to collect a rough estimate of the density of each plank to be compared to the planks' strength ratio. If teachers have several different classes conducting this experiment, it is interesting to compare and contrast the results from the different classes. Oftentimes, different classes come to different conclusions, which provides a wonderful catalyst for students to scrutinize varying experimental designs.

Before students are brought into the laboratory to make their planks, it is essential for them to fully understand the experimental design, the composite procedure adopted by their class, and exactly how to make and form the planks (see video in Resources), especially if they only have one 40- to 50-minute period to complete the work. Students within each group can be pre-assigned jobs so that when they walk into the lab they know what their roles are and every minute of laboratory time is used efficiently.

Day 3: Making planks

Example recipes for the composites are outlined in Figure 2. It is extremely important that the quantities in the recipes be measured by volume and not by mass. Although measuring by mass is more accurate and volume measurements can be prone to wide interpretations, the densities of dried wood can vary significantly between different tree species (see References for more information on wood densities). Since most sawdust sources contain many different tree species along with the fact that wood densities are much lower than flour, using volume instead of mass is a means to simplify and standardize the composite recipe so that each group produces enough composite material to create four planks without having to know the origin of the sawdust. Measuring by volume simplifies the calculations and makes sure the reinforcement (sawdust) does not overwhelm the matrix (dough) while allowing the percentages of sawdust-to-flour to be visually tangible to middle school students.

A classroom with six groups will need 2,000 mL of flour, 2,000 mL of sawdust, and 500 mL of table salt (see the Activity Worksheet for a full list of required materials). Students are required to wear indirectly vented chemical splash goggles when preparing the planks, and there should be a scoop supplied with the flour and sawdust to reduce the amount of dust created while students measure their materials. It is also helpful to provide each group with its own supply of salt, flour, and sawdust to measure, and to assign one student per group to watch the time and keep everyone on task.

Large quantities of sawdust for this project can be obtained from a local sawmill or hardware store. The sawdust received from large chain stores is usually a mixture from several different tree species, both hardwood and softwood. Using a mixture of sawdust is not a problem unless students are curious to com-

FIGURE 3 Sample data table for pooling class data

Group	Mass (kg)	Length (cm)	Width (cm)	Height (cm)	Volume (cm^3)*	Density (g/cm^3)*	Mass held (g)	Strength ratio*
1								
2								
3								
4								
5								
6								

* Requires calculation

You could also include a stress column. [mass held (g)/1,000 (g/kg) × 9.8 (m/s^2)]. Mass needs to be converted from grams to kilograms (g/1,000 = kg) when calculating stress.

pare a composite made from hardwood trees to a composite made from softwood trees. Samples of specific sawdust can be obtained from smaller woodworking operations or home-improvement enthusiasts. Alternatively, other materials could be employed in place of sawdust for the fiber of the composite, for example sand (particle), cotton strands, or other plant materials.

Teachers will need access to an oven, either at school (e.g., the home economics room oven) or home. A possible alternative is to use a small toaster oven that can be designated to the laboratory, although this will significantly increase the amount of time required to get all of the planks cooked. Even with access to a standard oven, if there are more than two classes a day participating in this study, it is recommended to stagger the classes due to the amount of cooking time required to bake the planks (students are not involved with this aspect of the experiment because of time constraints). The smell of the planks cooking is similar to that of bread baking. One concern about baking dough with sawdust in it is the possible outgassing of volatile organic compounds (VOCs). The release of VOCs while baking the planks at 150°C (300°F) is negligible when looking at the indoor and outdoor emission standards outlined in the Clean Air Act Amendments of 1990 and as measured by Wang and Gardner (1999).

Making the planks can be messy, but cleanup, disposal, and storage of materials are relatively easy. The flour, salt, and sawdust can all be disposed of in the classroom garbage can, and any extra materials can be stored in a labeled container (be sure to include "not for human consumption" stickers on both the flour and the salt). Students should expect to get their hands dirty when mixing and forming their planks, and each group should have at least one volunteer willing to get dirty during this investigation. Cleaning up after forming the planks can be done in the lab by simply washing hands with soap and water and wiping down counters with a damp sponge.

Small groups of three to five students can select or be assigned a sawdust-to-flour ratio, which they use to prepare four planks; 200 mL is enough flour/sawdust mixture to easily form four planks. Students should record all details of the mixture preparation (including whether extra water is added or extra flour is used on the hands when handling the dough) on the Activity Worksheet. Planks made from straight bakers dough (100% flour) act as the control (see the Activity Worksheet). Each group creates four planks using its sawdust-to-flour ratio (plank dimensions: 0.5 cm thick, 3 cm wide, and 20 cm long). Once the dough has been thoroughly mixed, students roll it out on the lab table until it is about 80 cm long and cut it into four strips about 20 cm long. The rectangle shape of the planks can be fashioned, on a cookie sheet that has been lightly greased with vegetable oil, using a ruler for measuring and creating straight edges (see video in Resources). This portion of the study takes one 40- to 50-minute period, including cleanup time, as long as

ACTIVITY WORKSHEET: TESTING WOOD-COMPOSITE STRENGTHS

Overview

Cutting-edge research at the University of Maine involves infusing polymer resins into fabrics, wood, concrete, ceramics, and other materials to produce stronger, more durable composites. These composites have been found to be extremely useful for marine, automotive, and construction industries, and more. Materials engineers are constantly researching how to modify building materials to create more desirable properties.

Objective

Create a stronger flour/sawdust plank composite as compared to control planks of straight bakers dough and determine the sawdust-to-flour ratio that produces the strongest composites.

Pre-lab

- Take the pretest.

Observations

- Classroom demonstration with dough planks (record observations):

  ____

  ____

- Create a wet mount and observe sawdust fibers under a microscope (record observations):

  ____

  ____

Hypothesis

Develop a hypothesis based on your observations regarding how the wood fibers will increase the strength of the dough planks and what ratio of sawdust to flour would be ideal to develop the strongest planks.

Experimental design

Describe the agreed-upon experimental design for your class.

____

____

Once an experimental design has been established, start mixing your wood composite. Be sure to wear indirectly vented chemical splash goggles.

Materials

Making planks (per group)

- 100 mL beaker
- 500 mL beaker
- 0–150 mL sawdust (depending on assigned ratio)
- 50 mL–200 mL flour (depending on assigned ratio)
- 50 mL salt
- 80 mL water
- Indirectly vented chemical splash goggles
- Ruler
- Cookie sheet
- Cooking grease/oil (enough oil to lightly grease the cookie sheets before forming planks)
- Mixing bowl

Testing planks (per class, unless otherwise noted)

- Balance (digital or mechanical)
- Ruler
- 2 desks of the same height
- 1-gallon bucket (per group)
- Masses/sand
- Safety goggles

Procedure for making planks

1. Your group will be assigned to make four planks with a particular ratio of sawdust to flour.

   Group calculations:

   Assigned percentage of sawdust to flour: __________

   - Calculate the amount of sawdust [200 mL × (___/100) sawdust] = __________ mL].
   - Calculate the amount of flour [200 mL – sawdust mL (calculated above)] = ________ mL].

2. Measure the flour, salt, and sawdust and combine in the mixing bowl. Add 80 mL of water. Mix with a spoon until dough begins to stick together and then knead with hands for a couple of minutes. If the

dough is not sticking together well, you may need to add a little more water. If additional water is required, add only 5 mL at a time and mention the extra water in the Experimental Design section.

3. Continue to knead dough/composite mixture with your hands.
4. Place the dough on the lab table and roll it out evenly into an 80 cm strand.
5. Using a ruler, divide the strand into 20 cm sections.
6. Place the 20 cm strands on a cookie sheet that has been lightly greased with vegetable oil. Form each strip of dough into 3 cm × 20 cm × 0.5 cm rectangle planks using a ruler to measure and create straight edges.
7. When you finish forming the planks, give them to the teacher, who will cook them at 150°C (300°F) for one hour.

Procedure for testing planks

1. Use a marker to number each plank (1–4), include the class and group number/name, and record on each plank the sawdust-to-flour ratio.
2. Determine the mass of each plank and write it in marker directly on the plank.
3. Make and record observations about each plank in the Observations and Results section. This would include the condition of the planks, cracks, bubbles, or any other types of deformities you notice before the planks are tested.
4. Make and record any other observations about the conditions within the classroom or lab, such as relative humidity, that may affect the testing results.
5. Place a plank between the two desks (there should be 2 cm of the plank resting on each side of the desk, and the 1 gal. bucket should hang from the middle of the plank). Wear safety goggles while testing the planks.
6. Add between 50 and 100 grams of mass at a time, depending on how sturdy the plank appears once the gallon bucket is hanging from the plank's center. It is important to wait about 30 seconds and listen carefully for cracking before adding more mass. If you hear cracking, you should wait until the plank settles before adding more mass (20 g at a time at this point). If the plank appears fine, you may continue to add 50 g of mass at a time.
7. Be careful the masses do not fall on the floor once the plank breaks, and "spot" the bucket (without touching it) at all times when testing. Keep your hands and feet away from any area where falling bucket might hit them.

Observations: Lab/classroom conditions

____

____

____

Test planks

Describe any modifications the class made to the above procedure.

____

____

____

Observations and results

Sketch sawdust fibers ×10	Sketch sawdust fibers ×40

Record your observations (qualitative and quantitative) for each plank that is marked with the corresponding number, its mass, and the sawdust-to-flour ratio.

Qualitative plank observations

Plank #1
Before testing______________________
After testing ______________________

Plank #2
Before testing______________________
After testing ______________________

Plank #3
Before testing______________________
After testing ______________________

Plank #4
Before testing______________________

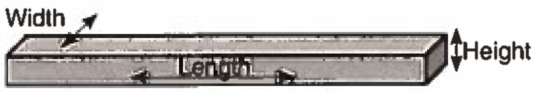
Quantitative plank observations (before breaking and after breaking)

Plank #	Sawdust-to-flour ratio	Length (cm)	Width (cm)	Height (cm)	Volume [L (cm) × W (cm) × H (cm)]*	Mass of plank (g)	Density [mass (g)/ volume (cm³)]*	Mass held by plank (g)	Stress (N) [mass held (g)/ 1,000 (g/kg) × 9.8 (m/s²)]*	Strength ratio [mass held (g)/ mass of plank (g)]*
1										
2										
3										
4										
Average										

* Requires calculation

After testing ______________________

- Mass is determined with a digital scale or double pan balance (g).



- Length, width, and height of the plank are determined with a ruler (cm).
- Volume is determined by multiplying length by width by height [length (cm) × width (cm) × height (cm)].
- Density is determined by dividing the mass of the plank by volume of the plank [density mass (g)/ volume (cm³)].
- The mass held by the plank is the most mass each plank held without breaking (g).
- The stress the plank experienced before breaking [mass held (g)/1,000 (g/kg) × 9.8 (m/s²)] = Newtons.
- The strength ratio is the mass held by the plank (g) divided by the mass of the plank (g) itself. The higher the strength-ratio value, the better the performance of the plank.
- Pool the averages for each column with the entire class (see Figure 3).

1. Once all of the data are collected and pooled, work with your group to create a bar graph that shows the sawdust-to-flour ratio as the manipulated variable and the average strength ratio as the responding variable.
2. As an extension, create an additional graph of your group's choice. The graph should be used to support your final claim.
3. The conclusion is one of the most important parts of the entire lab activity. It is important to make a claim, provide evidence from the results, and include scientific reasoning. It is also important to address any weaknesses within the experimental design and the testing procedure of the planks and provide suggestions on how to improve the research and future areas of research.

Conclusion (outline)

Claim: ______________________
Evidence: ______________________
Scientific reasoning: ______________________
Experimental-design weakness: ______________________
Testing-procedure weakness: ______________________
How to improve research: ______________________
Future area of research: ______________________

Comprehension questions

1. Explain why it is important to test several different planks with the same ratio of sawdust to flour. Why would you want to average the results of the strength ratios for each ratio of sawdust to flour? When is it appropriate to throw out results from one plank test and average the remaining results? Provide a clear example.
2. Do you think the results of the plank testing would be different on a rainy day (high humidity) versus a warm, sunny day? Explain.
3. Do you think a particle composite made with small granules of sand would be stronger than the sawdust fiber composite? Why or why not?

students are well prepared the day before.

Once the planks are completed, the instructor cooks all of them at 150°C (300°F) for one hour. This can be done after school or in the morning before class. Cooked planks will absorb water and become soft on days of high humidity, in which case it may be necessary to reheat the planks for 10 minutes prior to class in order to dry them. If this happens, the teacher must share with students that the planks were cooked for an additional amount of time. It would also be an excellent time to discuss how humidity might affect the strength of the sawdust-and-flour composite. Students should then be asked to record the relative humidity on the day the planks are tested. This information should be referred to if comparing results among classes or against the research done during different school years and can be used to address conflicting strength results with students' conclusions

Day 4: Testing planks

Prior to testing, students determine the mass of each plank, using either a digital or mechanical balance, and record this information on their Activity Worksheet. Students use markers to number each plank, record the mass of the planks, and write the ratio of sawdust to flour on each plank before testing. The density of the planks may be estimated by dividing the mass of the plank by the volume of the plank (length × width × height). All of these data need to be recorded in the table in the Quantitative Plank Observations section of the Activity Worksheet; students should also carefully inspect all four planks for cracks or weak points before testing and record these observations in the Qualitative Plank Observations section.

When testing the planks, students are required to wear safety glasses. One suggested way to test the strength of the planks is to set two desks of the same height approximately 15 cm apart from each other and place a plank across the gap with about 2 cm of either side of the plank resting on the desks. Record the mass of a 1 gal. bucket and hang it from the center of the plank that is being tested. Once it is clear the plank is capable of bearing the weight of the bucket, students may start placing weight within the bucket. Depending on how the plank reacts when the bucket is hung from the center of the plank, students could initially start loading between 50 and 100 grams of mass. It is important to wait at least 30 seconds and listen for cracking before adding additional weight. If cracking sounds are heard, students should wait until the plank settles before adding additional weight (about 20 g at a time under these circumstances). If cracking is not heard or the plank does not appear to be bending, students may continue to add 50 g of mass at a time. Students and teachers should exercise caution when adding weight, as once the plank breaks, the bucket and its contents will fall to the floor. Students should "spot" the bucket at all times to avoid injuries to their feet or the loss of the contents of the bucket prior to weighing. Once the plank cracks or breaks, students should record the mass of the bucket the planks held prior to breaking. There are no special disposal protocols required for the broken planks; they may be disposed of in the garbage can.

Students are expected to keep detailed records of their planks, including quantitative and qualitative data of each plank tested. These results should be recorded by students in the table in the Observations and Results section of their Activity Worksheet. The table there includes columns to record some of the obvious data, but students can add other observations they feel to be pertinent, such as the color of the plank or any deformities.

Day 5: Pooling classroom data and writing conclusions

The instructor can create a classroom spreadsheet in Google Drive so that all of the groups in the class can submit and pool their results (Figure 3). Each group will then see how its composite recipe compared to those of other groups and draw conclusions regarding composition versus performance.

Next, students create a bar graph with the pooled results (percentage of sawdust as the manipulated variable and the average strength ratio as the responding variable) and write a conclusion based on their data analysis. The format of the conclusion should be a statement that contains a claim, evidence from the results, and scientific reasoning. It is also important for students to address any weaknesses within the experimental design and the testing procedure of the planks, and to provide suggestions on how to improve the research and possible future areas of research. All scientific research is cyclical, and this composite activity may be approached in the same manner: By suggesting modifications to the activity based on the results, students are modeling how scientists make advances in research.

Discussion

It is of paramount importance for teachers to emphasize the process of students reporting their findings and devising conclusions. The results and conclusions of the activity can be reported by various means. For example, students can develop concept maps, give presentations, or write up laboratory reports. Indeed, it is in this stage of the experimental activity that students gain in-depth understanding and make connections to real-world applications. Internal reflection is an essential skill in STEM fields. Being able to effectively share and communicate results is a requirement. The authors recommend use of a laboratory report rubric in which student reporting is broken down into the following scored sections: title, problem, introduction, procedure, data, analysis, conclusion, and works cited (Ende 2012). Such an approach provides students with detailed guidance while writing and can be easily applied to concept maps and presentations.

The authors invite and would appreciate constructive criticism, feedback, and questions related to this or any other Forest Bioproduct Research Institute activities (see Resources for additional activities) teachers elect to implement. ■

Acknowledgments

The authors gratefully acknowledge the following teachers, who assisted in the piloting of the inquiry activities: E. Hayes and K. Littlefield of Troy Howard Middle School in Belfast, Maine; and J. Campbell of Leonard Middle School in Old Town, Maine.

The work reported in this paper was supported by National Science Foundation grants EEC-1063007 REU Site: Explore It! Building the Next Generation of Sustainable Forest Bioproduct Researchers; and EEC-0648793 REU Site: Explore It! Building the Next Generation of Sustainable Forest Bioenergy Researchers, and their associated RET Supplements.

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Resources

Advanced Structures & Composites Center (composite-research examples)—*www2.umaine.edu/aewc/component/option,com_frontpage/Itemid,1*

Barn swallow nest building project (time-lapse video of barn swallows building a nest)—*www.youtube.com/watch?v=hmFkYh8DcEY*

Forest Bioproducts Research Institute blog (includes in-depth lesson plans for this and many other activities)—*http://fbri.edublogs.org*

How to make and test wood composite planks (video)—*http://fbri.edublogs.org/files/2013/05/MakingTestingComposites-vmi7j0.mp4*

University of Maine Forest Bioproducts Research Institute—*www.forestbioproducts.umaine.edu*

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