Sinking and Floating 2.0

Using 3D printers to excite children in aftercare about science and engineering

By James Mendez, Kate Baird, and Greicy Patino

Picture this: a PhD chemist, PhD science educator, and a preservice Latina elementary educator walk into an aftercare program for primary and intermediate students from a rural school. These students are identified as low income and at risk and therefore eligible to participate in this school-provided aftercare. While across the state, these same educators engage a very different group of learners from a private school in afterschool enrichment for high achievers in grades 1 through 4. How does this odd collection of adults hook these diverse learners into the idea that they too can be scientists and engineers? The answer is to "update" a tried and true traditional classroom activity using 3D printers. We call it "Sinking and Floating 2.0—Engineering Design for all learners." We have embraced *A Framework for K–12 Science Education*'s definition of engineering and technology as referenced in the *Next Generation Science Standards* (NGSS) appendix 1 on Engineering Design (NGSS Leads States 2013), which states, "We use the term engineering in a very broad sense to mean any engagement in a systematic practice of design to achieve solutions to particular human problems. Likewise, we broadly use the term technology to include all types of human-made systems and processes—not in the limited sense often used in schools that equates technology with modern computational and communications devices. Technologies result when engineers apply their understanding of the natural world and of human behavior to design ways to satisfy human needs and wants" (NRC 2012, pp. 11–12). The children from both settings were engineering boats to solve their version of a real-world problem using technology.

FIGURE 1

Flashforge Dreamer used in this project. Notice touch-interface and enclosed design, ideal for young students.

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DESCRIPTION OF THE PROJECT

We were invited by each aftercare to come and help build enthusiasm for engineering and technology with the students. The 3D printer seemed to be a great engagement tool. Quickly the idea to build on the traditional "sinking and floating" design challenge came to mind. In the traditional activity, students are given minimal supplies (clay, paper, aluminum foil, and so on) and charged with the task of finding a boat that will hold the greatest number of pennies without sinking. In many classrooms, this is often more of a random trial-and-error process than a structure design challenge. Our plan was to start with this challenge and then extend the challenge to include the concept of building prototypes and models as part of the engineering process.

3D PRINTING AND SAFETY CONCERNS

During the testing process, be sure to clean up all spills to avoid slips.

There are several types of 3D printers on the market today; we used a fused filament system that melts plastic in layers to form three-dimensional objects. The model used in this project (Flashforge Dreamer) is currently available for approximately $1,000, but we regularly use a less expensive model (Flashforge Finder, $300) with no difficulties. The build plate and nozzle get hot, prompting us to use and recommend a system with a door that can be closed when working with younger students (Figure 1).

Recent research also suggests that using some common plastics at high temperatures with 3D printers can emit potentially harmful particles. However, using PLA (polylactic acid) at 200°C in a well-ventilated room, as was done in this project, effectively limits this danger (Stabile et al.).

STUDENT DEMOGRAPHICS

This project took place in aftercare in the schools the students attended. Each project occurred over the course of four sessions.

School 1 The grade 2–5 students were part of an aftercare program from a private urban Indiana school for students whose parents work late. The school services a primarily Hispanic population (68%) with White (27%) and Multiracial (4%) representing the remainder of the students' ethnicity (NOTE: Indiana uses Multicultural to mean multiracial). Most of the students are on food support through federally funded free (79%) or reduced (10%) meals while in school.

School 2 The grade 1–4 students were part of an existing high achievers group identified by teachers at the rural Indiana public school. The home school is 92% white, 3% Hispanic, 3% Multiracial, 1% Black and 1% American Indian. Just over half (54%) of the students receive meal support (40% free and 14% reduced).

Our goal was to demonstrate engineering design process through an engaging real-world dilemma—How do we move the most products with the fewest number of trips of the boat. This is a clear practical problem as we all use products and services that are part of the global economy which is driven by worldwide manufacturing systems. Much is discussed in contemporary public media about the cost of transporting goods and materials, providing evidence of the importance of this topic to the students. Time was short and the children were so interested in the experiences of the challenge, necessitating us to focus on the design aspects of the project rather than real-world connections. We hope to build locally relevant stories that will help connect the need for better engineering and design to the student's everyday lives in the future.

WEEK 1: GETTING STARTED

The first day was all about introducing the project and building interest in the design challenge. A 3D printer was brought into a room with the students. To demonstrate how easy 3D printing is, a student was chosen to start the printer and make a prearranged example. A random student was chosen to show that any student could work this machine.

With the 3D printer running in the background, the students were told they were going to make a boat. As an example of an engineering challenge, students needed to construct a boat that would hold the greatest number of pennies using only the materials provided. Students were given different materials including aluminum foil, modeling clay, and white copy paper. This was left open-ended with students choosing which material to start with. Most students started by drawing a model and then attempting to replicate it with one of the materials. If a boat failed, or succeeded, instructors were present to suggest alternatives and push them to try something new.

We began the discussions based on materials developed by NSTA past president, Karen Ostlund, which we experienced at a NSTA conference (2016). The steps we focused on were identify/define the problem, identify and describe the system, generate design solutions, use newly evolved technology to refine model into prototype, test and redesign, share the results. This allowed us to focus on *NGSS* science and engineering practices. The students used session one time to explore possibilities in a hands-on situation that supported drawings and designs that would come in the subsequent sessions.

PRACTICE 1 ASKING QUESTIONS AND DEFINING PROBLEMS

Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution. (NRC 2012, p. 56)

PRACTICE 2 DEVELOPING AND USING MODELS

Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system (NRC 2012, p. 58).

PRACTICE 3 PLANNING AND CARRYING OUT INVESTIGATIONS

Students should have opportunities to plan and carry out several different kinds of investigations during their K–12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions. (NRC 2012, p. 61)

The creativity among all children overflowed during this first session. Once their prototype was complete, they were all able to test their boat in a small tub of water. As the prototypes were being tested, students discovered that some materials worked better than others did. When their clay boats with thick walls immediately sank (Figure 2) they were asked: "Why did this happen?" and "What could you do to make it float better?" The students then engaged in the redesign and test phase of the process.

After everyone was given the chance to test a model, a group discussion proceeded. Students were again asked what worked and what didn't work. Supporting the idea that failure is part of the process and important to engineering, the key part to this discussion was getting the students to ask why and to scaffold what was to come next session. At the end of this meeting, we told the students that we would be back next week to use the 3D printers to make boats… to much excitement! By this time, the 3D printer started at the beginning was done so the students had an idea of what the end product could look like by viewing the completed demonstration piece. The groundwork had been laid for the students to see themselves as engineers and scientists who use technology as part of the design process.

FIGURE 2

Students observing clay boat with thin walls floating while two thick-walled boats sit on the bottom of the tub.

WEEKS 2 AND 3: DESIGN AND REDESIGN

This second session was dedicated to completing the design process of the boat model that would sustain the maximum number of pennies. Students were scaffolded with four different boat designs, printed on 3D printers, to inspect: a pontoon boat, raft, tugboat, and speedboat. Once again the students were given a tub of water and tasked with testing these boats. The goal was the same for each group but interestingly, some groups came to very different conclusions. Many groups chose a boat based on how it looked rather than how it performed when tested (Figure 3). However, many students preferred the speed boat because it "looks like a real boat." One lesson we learned between sessions was that many students had minimal personal experiences with diverse boat styles. To address this, we spent time at the beginning describing the different types of boats and noticed a considerable shift to the pontoon boat, which previously received very little attention from the students.

Once all of the boats were tested, each group was instructed to pick a design that they would modify for next week. Using a free modeling program (OpenSCAD), students were asked to make changes to their boat's design. Many students noticed that the sides were open in the pontoon boat and wanted to close them while others saw that the speed boat tipped over so wanted to make it wider. The modeling program allowed them to make changes and immediately see the result (see Internet Resource). Most of the students were able to quickly learn to use the modeling program, but a worksheet was also used to ensure that the younger students (mostly first graders) were not left out (Figure 4). The primary purpose of the worksheet was to allow these younger students to communicate their ideas to the older students or teachers who would then assist them in implanting them in the computer program.

At the end of the second week, each group was instructed to pick a final design that would be printed and brought back the following week. As facilitators, we took it upon ourselves to never say no to a student's idea.

"Can you make it green?" "Sure."

"Can we put a flag on our boat?" "Why not."

"What if we make it upside down?" "Let's see."

By the end, they were clearly testing us but we still made it happen. "Can we put cannons here, here, and here?" one student asked. "Of course, but that might not help it hold pennies" was our response, "But it will look cool!"

Just seeing a 3D printer in action was enough to get most of the students excited about technology, but by actually making their own designs these students were able to see that the possibilities are endless. Currently 3D printing is a slow process so while the designs were finalized at the schools, undergraduate students printed most of the boats at a local university and brought them in the following week.

FIGURE 3

Starting boats chosen by groups at School 1 (black) and School 2 (red).

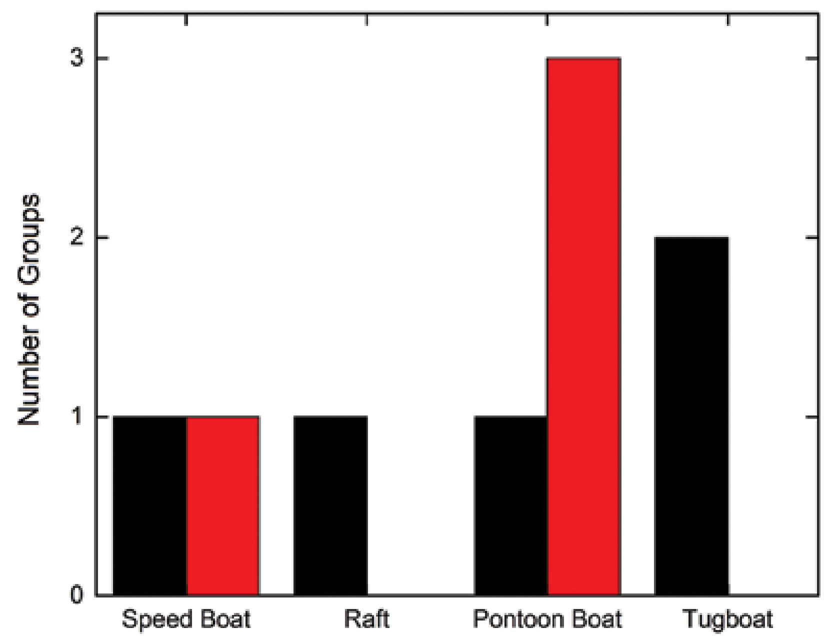
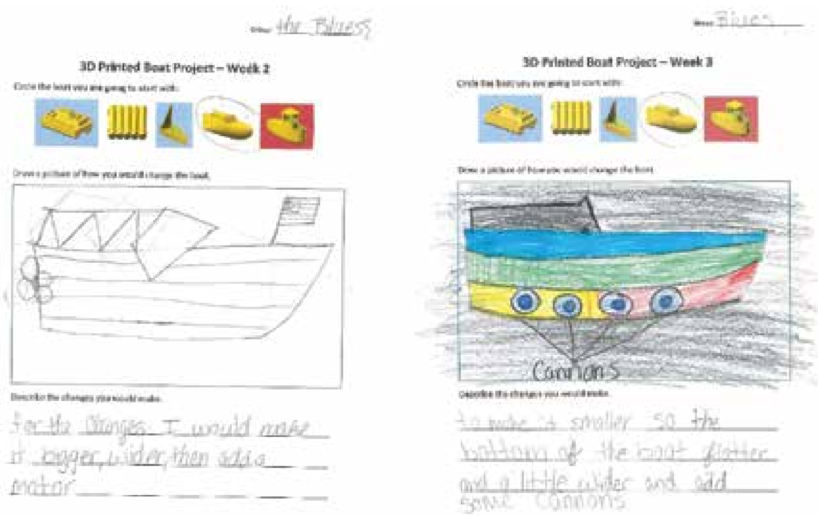


FIGURE 4

Younger students were given the option to draw and describe their boats instead of using the computer program.



In week 3, the students tested their boats and once again made changes to their designs using the modeling program. Excitement, enthusiasm, and eagerness to test the boats was evident in every child's face when they were shown the boats they had designed. By this time, most of the groups were familiar enough with the process that they needed very little assistance with the technical aspects.

WEEK 4: THE FINAL TEST

The final test was projected on a giant screen and all of the students in aftercare at School 1 and all of the students at the school at School 2, not just those that participated in the program, were invited to watch. The project was explained to everyone and each group added pennies to their boat until it inevitably sank. Many boats had changed dramatically over the weeks, while other stayed mostly the same (Figure 5).

Once the last boat was tested, each participant was given a miniature version of their boat and the winning team received a trophy created by the 3D Printer. After continuous cheers and applause, every single student present at the convocation was able to step forward and take a look into the spectacular 3D Printer.

LESSONS LEARNED AND NEXT STEPS

We expected students to be familiar with the local lakes, rivers, creeks, and boats in general. However, this was not the case. To make up for this deficit, more time than expected was spent explaining how boats work. The explicit connection of water travel to the history of our area and to our future will need to be more explicitly addressed in upcoming workshops.

Perhaps the most interesting part of this project is the lack of achievement difference in student success between the two groups. Although no formal assessment was conducted, the students from the urban, 73% minority, self-selecting group mirrored the achievement of the rural, 8% minority, high achieving learners. Both sets of students in each aftercare were equally engaged in this project and excited to talk with their peers and us about the success or shortcomings of the different designs. All of the groups from both programs completed the entire project and seemed genuinely happy when we showed up.

Another wonderful aspect of this program is that it allows students to explore and learn by working with their peers, making it ideal for students with English as their second language. In the future, we plan to focus on this group and use a design program with a graphical interface (such as *www.tinkercad.com*) better suited for a younger audience. ●

FIGURE 5

One of the original boats (left) and redesigns from week 2 (middle) and week 3 (right).

INTERNET RESOURCE

OpenSCAD
www.openscad.org

REFERENCES

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James Mendez (*mendezja@iupuc.edu*) is an assistant professor of chemistry, and **Kate Baird** is a former clinical assistant professor, both at Indiana University – Purdue University Columbus (IUPUC) in Columbus, Indiana. **Greicy Patino** is a former student at IUPUC and currently a teacher at Clifty Creek Elementary School in Columbus, Indiana.

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard

3-5-ETS Engineering Design

www.nextgenscience.org/dci-arrangement/3-5-ets1-engineering-design

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectation listed below.

Performance Expectation

3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Analyzing and Interpreting Data **Constructing Explanations and Designing Solutions**	Students build models to test different materials. Students evaluate the effectiveness of different materials for building a boat. Students use computer modeling to design a boat that could not be made by hand.
Disciplinary Core Ideas	
PS1.A: Structure and Properties of Matter Different properties are suited to different purposes. A great variety of objects can be built up from a small set of pieces.	Students relate boat design aspects to performance.
ETS1.C Optimizing the Design Solution Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.	Students describe the relationship between the boat design and the ensuing model.
Crosscutting Concept	
Structure and Function	Students determine the best shape and size of the boat to hold the most pennies.

NSTA Connection

Download instructions for making a boat and an assessment at *www.nsta.org/SC0719*.