Printing the Playground

Early childhood students design a piece of playground equipment using 3-D printing technology.

By Stephanie Wendt and Jeremy Wendt

With grant funds in play, teachers at Prescott South Elementary School in Cookeville, Tennessee, were looking for innovative ways to engage students in new and exciting STEM experiences. One outcome was the purchase of a MakerBot 3-D printer. The printer provided opportunities for previously inconceivable projects. Teachers submitted ideas about ways to interest students in 3-D modeling processes while meeting standards and school objectives. The school STEM advisory committee posed a vision that challenged both teachers and students: Kindergarten and first-grade students were charged with designing new playground equipment to create a solution to a problem: The school playground was in need of additional equipment. Students jumped at the opportunity to solve an issue they were dealing with daily.

This project would engage students in Science and Engineering Practices as described in the *Next Generation Science Standards* (see "Connecting to the Standards," p. 47). Several tech-savvy teachers (and two middle school students) were trained to use the printer and 3-D modeling programs such as SketchUp—chosen as the primary implementation software due to its ease of use and free access for educators. In turn, they became facilitators and troubleshooters for student learning projects.

The playground project began with a week of interdisciplinary planning by teachers across the K–1 classes, followed by the weeklong implementation. For the culminating project, students presented the principal with a 3-D printed model of the playground equipment selected from their designs. In turn, the principal ordered the equipment for the school. Throughout the authentic learning experience, the students engaged in Science and Engineering Practices: They asked questions and defined problems, developed and used models, planned and carried out investigations, and constructed explanations and designed solutions. The interdisciplinary project incorporated literacy, science, math, and physical education. In addition, throughout the unit, teachers reported an increased level of engagement.

It is important to note that although this engineering design challenge culminated with the use of a 3-D printer, the process is still valuable for students who do not have access to this technology. If the support structure for 3-D printing is not in place in the school district, then local universities and 3-D printer companies are other possible resources for providing training and support. For this project the 3-D printer was obtained through a STEM grant, but could be purchased through a variety of sources. The school PTO, *www.donorschoose.org*, and *www.grantwrangler.com* are all reasonable avenues for funding a 3-D printer (see Internet Resources). Collaboration with local businesses and universities could provide opportunities for 3-D printing as well. A business or university with a 3-D printer could easily receive the file and print the object for the school. Video conferencing could even be used to allow students to view the process and speak to the operator as the process is happening. 3-D printing software is rapidly evolving and making improvements. Based on the experiences of the local school and university discussed in this article, companies are generally very responsive to requests for assistance and are eager to expand their uses for implementation in the K–12 setting. The 5E Model, developed by BSCS (Bybee et al. 2006), was one of the foundational approaches for the project.

Engage

In order to generate excitement about the project, the principal wrote a letter to the kindergarten and first-grade classes requesting their help to design new playground equipment for their school. After this introduction, the students were shown videos, pictures, and examples of children on various types of playground equipment to help them brainstorm ideas. First individually, and then in small groups, students journaled about specific equipment and activities they desired. They described their ideas creatively in writing and with annotated student drawings (Figure 1). These included comments such as: "It needs to be wider at the bottom to hold more people," "The bars need to be close together for us to reach," "If we all stand next to each other, how big does it need to be to hold us?" and "Should we use plastic or metal on our creation? We want it to last a really long time!"

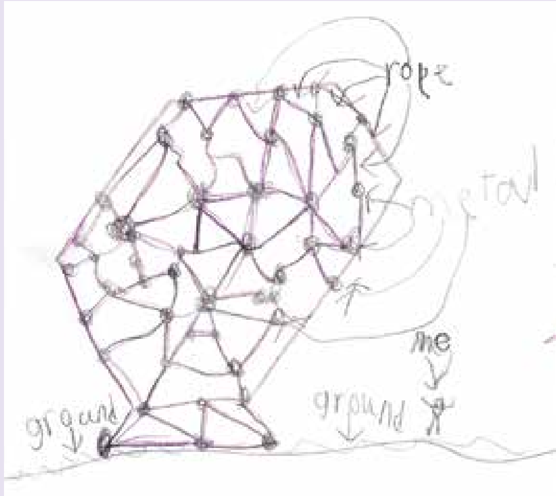
According to Page Keeley (2008), "Annotated Student Drawings are student-made, labeled illustrations that visually represent and describe students' thinking about a scientific concept." This concept, in addition to Think-Pair-Share (see more in the explain stage), is one of the 75 Science Formative Assessment Classroom Techniques (FACTs) from Keeley's book. Students were engrossed in the ideas of equipment design and engineering, while employing higher order thinking skills. In this stage of the 5E model, students were introduced to initial steps of the engineering design process (Lachapelle and Cunningham 2007) by asking questions and defining problems while imagining equipment on which they wanted to play.

3-D Printing

What exactly is a 3-D printer and how does it work? The small-scale 3-D printer has evolved from large-scale "additive manufacturing." For public sector use, this translates to adding materials in layers to construct a solid, three-dimensional object. Essentially, once you've created or downloaded a 3-D digital model, you send it to the printer through USB or wirelessly. The device then heats and melts string-shaped plastic from a spool in layers onto a platform to build the model. The device makes passes similar to an inkjet printer, depositing the plastic material. The process can take a few minutes or several hours to complete, but the possibilities are endless.

FIGURE 1.

Annotated student drawing.



Explore

The teachers facilitated and moderated discussions to help the students visualize the complex processes that architects and engineers follow to make project ideas a reality.

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In the explore stage, students use manipulatives to develop and build their playground models.

The *NGSS* Science and Engineering Practice Developing and Using Models, states "In engineering, models may be used to analyze a system to see where or under what conditions flaws might develop, or to test possible solutions to a problem. Models can also be used to visualize and refine a design, to communicate a design's features to others, and as prototypes for testing design performance" (NGSS Lead States 2013, p. 6). In this stage, the students began drawing and designing more complex variations of their ideas. Throughout the 5E process, and especially during this stage, teachers incorporated mini lessons that addressed students' questions on topics such as geometric shapes, addition, subtraction, and other subjects as needed. For example, CCSS.Math.Content.K.G.B.4 (Analyze, compare, create, and compose shapes) was addressed in a mini-lesson with pattern blocks and geometric shaped manipulatives. Students described two- and three-dimensional shapes' similarities, differences, and attributes in small groups and with the class. In first grade, teachers and students addressed CCSS.Math.Content.1.G.A.1 (Reason with shapes and their attributes) while constructing triangles, rectangles, and other geometric shapes out of classroom materials and manipulatives. Students defined the specific attributes of shapes individually and within their small groups. Teachers incorporated flipcharts and internet resources on the interactive white board as part of whole-class instruction.

Once students demonstrated their understanding of the basic geometric shapes and concepts, they were given the opportunity to take all of the individual lesson components and compile them into a working model. Students synthesized all of the information from the challenges, lessons, and processes into a physical reality. This was accomplished by using manipulatives such as gumdrops, marshmallows, and toothpicks to develop physical models of the playground equipment sketches. During their investigation, students worked like engineers to explore different heights and bases for their models. They experimented to learn which designs were strongest and discussed their ideas in their groups and with the teacher.

Interactive Resources for 3-D Printing

For lower grades, students can use design apps for the iPad that will print to a 3-D printer. Different 3-D printers have product-specific software, but general design software files can be exported to individual printers. Blokify is an app that lets users create "blok" based models through a guided building experience or free-form. The completed model can then be sent to the 3-D printer for creation. Several websites, such as *www.thingiverse.com*, have hundreds of models available for download that can be transferred to a 3-D printer for creation.

SketchUp is a 3-D modeling program that is used by architects, engineers, interior designers, and many other professionals. The software has an online, open-source repository called 3-D Warehouse, with free, downloadable models. A freeware version, SketchUp Make, is available to the public. Educators can apply to receive the full-featured version of the software, SketchUp Pro, free of charge (see Internet Resources).

Explain

With guiding questions from the teachers, the students assessed the current playground equipment. They brainstormed innovative possibilities for improving the existing playground, including the best materials, structural designs, safety considerations, and costs for their ideas. In this phase of the project, students continued planning following the Think-Pair-Share model. According to Keeley (2008), Think-Pair-Share combines thinking with communication. The teacher poses a question and then gives students time to think about the question individually. Students are then paired with a partner to discuss and share their ideas in small-group or whole-class discussions.

Each group had one member assigned as the group note-taker to summarize their collective ideas. They determined their current playground's strengths and weaknesses, working through a number of possibilities concerning a variety of equipment. The students' progress was monitored and prompted by teachers through guiding questions such as: Is wood, metal, or plastic the best material for your design? How many children can play on your model at one time? Is your model too tall for kindergarten and first-grade students? Throughout this stage, students

constructed explanations and designed solutions to help address several aspects of playground design: the number of students that could play on one piece of equipment at a time, safety issues, materials needed, appropriate size and type of equipment based on student age, aesthetic properties, and durability. The teachers guided students to carefully consider each of these points during the planning for their project, keeping the end product in mind.

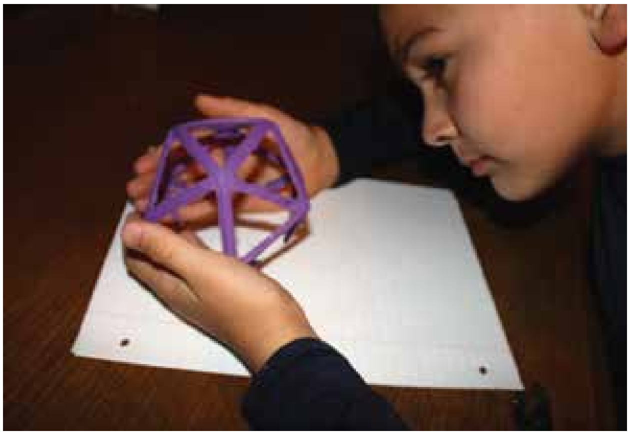
Elaborate

After small-group discussion about the models, groups presented their designs to the full class. Students were asked to explain the thoughts, ideas, and processes behind their designs. The thought processes of the students were observed in their presentations: "If we build it really tall, I could probably see all of my friends from the top; If we build it out of metal, it will last longer than something made out of wood; We can't all play on one thing at the same time, because it would break if we were all on it." This step in the process allowed students to experience engineering design in an authentic manner. Following their presentations, a teacher who had attended the 3-D printing workshop transferred ideas from students' plans to SketchUp, enabling students to view their conceptual designs in the digital environment. Student designs were selected and constructed based on the most realistic and viable options for new equipment. These samples were passed around the classrooms for the students to analyze and view. From the many geometric designs and shapes presented, the principal selected three realistic choices. The students voted on a variation of an *icosahedron* as their final choice.

Evaluate

Formative assessment was used throughout the project. Teachers kept students on task by asking "Are you meeting the objectives of the project?" "Have you stopped and discussed improvements you could make?" and "Are you following directions?" Students were asked to make changes and adaptations to their designs based on group collaboration and feedback from teachers. Assessments included:

- Assessment of addition and subtraction through the use of tens frames
- Formative assessment through the use of NCTM's Illuminations interactive website (see Internet Resources)
- Formative assessment through the use of the Science Kids' interactive simulations to determine properties of materials (see Internet Resources)
- Students were asked to clearly define the problem orally to the teacher before developing models
- Using their models and drawings, students successfully communicated solutions with group members and then to the whole class
- Students made bar graphs to represent the data collected from student votes
- Summative assessment of students' knowledge of geometric shapes and measurement skills



A student examines a 3-D printed playground equipment model.

Looking forward to the end result of playground construction and its impact on the school, students were very involved and took ownership of the project. The principal made announcements to the school throughout the process and gave regular updates to the classes. Students remained eager each day to hear about the next step in the project's progress. Students were overheard explaining the mission and excitement of the project and the new playground: "This is hard being an engineer, but it's fun!" "My brother won't believe that we were the ones who made the playground." The culminating event of the project came when the principal selected student designs to be ordered and purchased for the school playground. A large rope climber with geometric shapes that incorporated the kindergarten and first-grade students' designs was installed in May on the elementary playground. The students and faculty celebrated their success with an unveiling and dedication.

Reflections

As a first-time project, the planning to implementation period was brief, and more time could be allotted to the hands-on and exploratory model creation. Approximately two weeks were dedicated, but three weeks would have been more accommodating. Additional support and outside perspectives would be beneficial to the project. For example,

involvement and collaboration from an engineer or architect would help in understanding the design processes. If present, preservice teachers from a local university could help with the project by increasing the individual attention to students. Preservice teachers could be prepared for this type of project by replicating the process in the college classroom. They would understand and be able to implement the project in many settings, but having the experience and knowledge would prepare them for the classroom.

Opportunities

K–1 grades often are overlooked when advanced projects are undertaken. The playground project demonstrated that this age group benefitted by being part of the process. This foundation of critical thinking and problem solving can be built in the early grades to enable advanced processing and knowledge base in the later grades. In higher grade levels, problems can become increasingly complex. For example, fourth-grade students at the school addressed the problem of noise in the cafeteria by designing sound tile samples on the 3-D printer. The 3-D printer aids in the scale creation of these and many other types of models. Even without access to a 3-D printer, engaging students in this process creates an environment for excitement and opens doors to the future. Teachers and students can use resources available to them such as modeling clay, toothpicks, candy, tinker toys, Legos, and other classroom manipulatives to assist in problem solving. Professionals in STEM careers work to solve similar problems daily. What better time is there to introduce a love for STEM than in childhood? ■

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References

Bybee, R., J.A. Taylor, A. Gardner, P. Van Scotter, J. Carlson, A. Westbrook, and N. Landes. 2006. *The BSCS 5E instructional model: Origins and effectiveness.* Colorado Springs, CO: BSCS.

Keeley, P. 2008. *Science formative assessment: 75 practical strategies for linking assessment, instruction, and learning.* Thousand Oaks, CA: Corwin Press.

Koch, J. 2011. *Science stories: Science methods for elementary and middle school teachers.* Belmont, CA: Wadsworth, Cengage Learning.

Lachapelle, C.P., and C.M. Cunningham. 2007. Engineering is Elementary: Children's changing understandings of science and engineering. In *ASEE Annual Conference & Exposition* (March): 33.

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

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

K-2-ETS1 Engineering Design

www.nextgenscience.org/k-2ets1-engineering-design

Science and Engineering Practices

Asking Questions and Defining Problems
Developing and Using Models

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- A situation that people want to change or create can be approached as a problem to be solved through engineering.

ETS1.B: Developing Possible Solutions

- Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem's solutions to other people.

ETS1.C: Optimizing the Design Solution

- Because there is always more than one possible solution to a problem, it is useful to compare and test designs.

Internet Resources

Donors Choose
www.donorschoose.org
Geometric Solids
http://illuminations.nctm.org/Activity.aspx?id=3521
Grant Wrangler
www.grantwrangler.com
MakerBot Thingiverse
www.thingiverse.com
Measuring Me
http://illuminations.nctm.org/Lesson.aspx?id=2756
NCTM's Illuminations
http://illuminations.nctm.org
Science Kids
www.sciencekids.co.nz/gamesactivities/materialproperties.html
SketchUp
www.sketchup.com