Creating a Prosthetic Hand

3D Printers Innovate and Inspire a Maker Movement.

By Kristin Leigh Cook, Sarah B. Bush, and Richard Cox

The power of 3D printing technology has grown exponentially in just the past few years—people around the world are using 3D printers to prepare food, create tailored clothing, build cars and homes, and advance the medical field in ways that never seemed possible (Martinez and Stager 2013). Even in classrooms across our nation, 3D printers have become increasingly common because of their affordability and ease of use. Given the focus the *Next Generation Science Standards* (NGSS Lead States 2013) and the *Standards for Technology Literacy* (ITEA 2007) place on engineering and design, 3D printers are enabling students to create tangible design solutions and inspire models of applied science, technology, engineering, arts, and mathematics (STEAM).

Teachers have recently begun to capitalize on the benefits of using 3D printers to facilitate makerspaces—spaces where people can gather to create something or learn how to—in elementary classrooms. Allowing young students to create and innovate their own design solutions to real-world problems emulates how real science and engineering is done. In this article, we explore how one teacher employed 3D printing technology with fourth-grade students in a STEAM lab to design and create a prosthetic hand. Mr. Smith's (pseudonym) vision for the STEAM lab, which he conceptualizes as a makerspace where learners of all abilities use multiple disciplines to solve problems, is to inspire a love of learning in students and to create a space for authentic inquiry about their world.

Students take measurements of arm dimensions prior to building their design.

Designing a Solution

The project-based unit resulted from an identified need in the community: a student at a school in the district who was born without a hand was having difficulty logging onto the computers at school and needed help. Specifically, she needed the ability to press the Control + Alt + Delete keys at the same time—which are on opposite sides of the keyboard. Although at a different school, Mr. Smith was approached by the girl's teacher and parents who knew about his STEAM lab and resources. Beyond having access to a 3D printer, the STEAM lab was a classroom known for inquiry-based learning about real-world problems. Mr. Smith decided this would be an authentic opportunity to engage students in the design and engineering process called for in the *NGSS*. Although the girl and her school remained anonymous, Mr. Smith's students readily accepted the challenge of designing, building, and printing a prosthetic hand and arm to help her with school-related tasks.

Students attended Mr. Smith's class as a special area five days a week for 50 minutes during a six-week period in which they undertook engineering projects as a way to integrate STEAM content. Although Mr. Smith conducted this unit in a STEAM lab, this project could be embedded in a traditional elementary classroom as it incorporates many content area standards in the core subjects of science, mathematics, and technology. Similarly, if teachers do not have access to a 3D printer but still want to incorporate the research and design aspects of this unit in their classrooms, they can locate the nearest 3D printer to their school through the online digital design site, Tinkercad (see Internet Resources). Although Mr. Smith conducted this project over the course of six weeks due to the structure of the STEAM lab, teachers could conduct similar projects in a shorter time frame given their specific students and classroom structures.

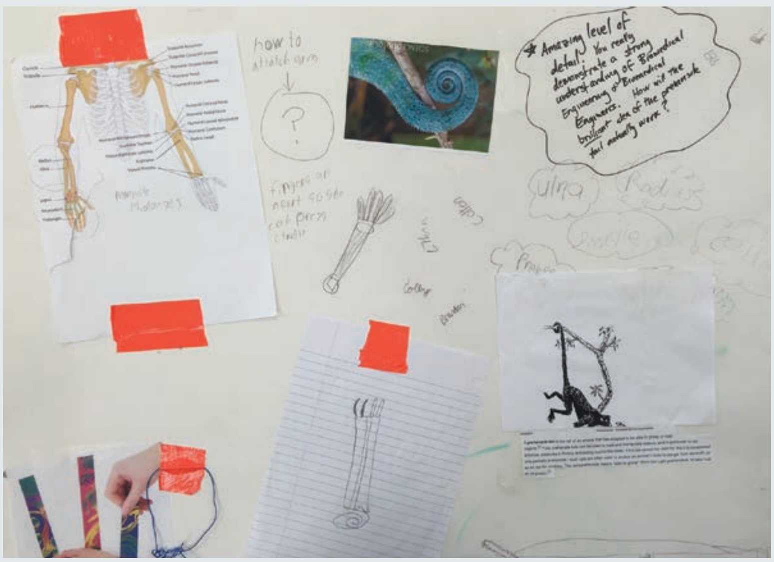
Week 1: Building Empathy and Defining a Purpose

Because it was important to begin this project by understanding the potential for meaningful impact, Mr. Smith presented the problem to his students and took care to build empathy for the girl who needed their help. In doing so, he asked his fourth graders to consider what it might be like to have just one arm instead of two. It was important to set a tone of respect, so Mr. Smith emphasized the importance of equal access and briefly reviewed the Americans with Disabilities Act (see Internet Resources).

To explore equal access, students inventoried the school grounds—moving around the school and attempting to perform simple tasks such as using the restroom, washing their hands, opening doors, and logging onto computers with only the use of one arm. Through this guided exploration, students became aware of how difficult simple tasks are with only one arm and understood the seriousness of the project on which they were about to embark. They began questioning what solutions the school might offer to help students with physical disabilities (e.g., installing automatic doors and motion-activated faucets, lowering bookshelves in the library). Students completed an Accessibility Analysis and Evaluation form (see NSTA Connection), which asked them to identify areas of concern throughout the school, and submitted their results and recommendations to the principal. Setting the stage with this purpose-building activity inspired awareness of the scope of the problem while building excitement and a sense of purpose to which students could stay connected and motivated by throughout the six-week project.

FIGURE 1.

Team schematic of researched elements for design.



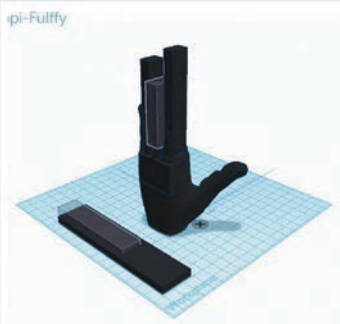
Week 2: Guided Research

Students were then separated into self-selected teams (five different design teams of 4–5 students each). Within each team, students first used online resources to research prosthetic hands and hand/arm anatomy as they brainstormed, sketched, and designed independently for about 30 minutes. The students then collaborated to develop one team design using the most promising ideas from each student's independent work, which necessitated their articulation of why their design was chosen and why it should be included in the final group design.

In selecting features, students were prompted to consider functionality, usefulness, and feasibility with regard to building. Teams began conducting research and documenting their findings on artificial body parts, the skeletal system, prosthetics, and inventions on a large poster board. Sources for research included classroom books such as *Engineering is Elementary Biomedical Engineering* unit "Erik's Unexpected Twist: Designing Knee Braces" (see Internet Resources). Students used Google Safesearch to peruse ideas for developing a prototype online. At the end of the week, teams developed a schematic drawing on poster-sized paper based on their group vision for their prosthetic (Figure 1).

FIGURE 2.

Sample 3D blueprint created on Tinkercad.



Week 3: Creating a Blueprint

Engineers and designers always have a plan. Students learn that while it's fun to tinker, create, and explore on the fly, the level of seriousness of this project and its implications demanded planning out as much as possible, including making a blueprint or visual aid to guide construction and evaluation. Students from each team were asked to create a blueprint for their design on Tinkercad, an online site for creating digital designs that are ready to be 3D printed into physical objects (see Internet Resources). All students created a 3D model on Tinkercad (Figure 2) and instructional prompts included:

- How can we make something both functional and aesthetically pleasing?
- How can we activate our schema and use ideas (from nature, from our daily lives) to inform our designs?
- How can we translate a 2-dimensional idea into 3-dimensional space?

Tinkercad is free, so teachers can set up one account and share the username/password with the students (Tinkercad requires anyone over the age of 13 to use an e-mail to create an account). Teachers can sign up students under their classroom account or receive parental permission for each student to have their own account. A classroom account allows teachers to keep track of all student designs and offer formative suggestions.

Week 4: Building the Prototype

Given a total classroom budget of \$30–\$50 for materials, teams developed a supply list of desired resources that weren't already readily available in the STEAM lab. Once

FIGURE 3.

Prototypes for a prosthetic hand.

all supply lists and budgets were approved, Mr. Smith visited a home improvement store website to order these specific amounts of materials. Because students knew the measurements for the desired prosthetic hand, they determined the appropriate sizing for arm design and attachments of the prosthetic to the body. Once the materials arrived, each team built a prototype (Figure 3). During the prototype phase, students tinkered and explored. Because many had never used small tools like door hinges, PVC pipe, and foam insulation before, it was essential to allow time for exploration of the building materials. Safety considerations included a discussion of proper handling of materials and use of gloves and goggles. During this phase, students evaluated their prototype daily with a rubric in terms of the development and application of new and previous knowledge toward our larger design goal (Table 1).

CAUTION

Week 5: Public Relations

Next, teams presented their prototype to the class and other stakeholders to make arguments for and justify their design. The principal, the district technology integration specialist, other teachers, and classmates served as the audience for these presentations. The goal of the presentations was for each team to contribute ideas to an overall design for the next phase in which the teams merged into one company. Audience members voted on components of each design from each

PHOTOS TAKEN WITH STUDENT PERMISSION BY JOHN ROBERTS, BULLITT COUNTY PUBLIC SCHOOLS COMMUNICATION DIRECTOR.

Students meet as a group to discuss their prototype design.

TABLE 1.

Team schematic of researched elements for design.

Criteria	Proficient	Developing	Novice	Score
Development: Does my work show how my understanding of this topic changed over time?	5: I edited this work several times. This work shows my personal understanding in a clear way.	3: I edited this work once and it shows my basic understanding of this topic.	1: I did not edit this work and it does not show my understanding of this topic.	
Application: Does this piece make natural connections across ideas to create a work with an original message?	5: My work shows that I can make connections with 2 or more ideas to create something original.	3: My work shows understanding of the topic, but the connection to other ideas is not evident.	1: I did not make any connections to other ideas in my work and it does not show originality.	

FIGURE 4.

3D printed prosthetic hand.

FIGURE 5.

Safety precautions for 3D printing.

- Print nozzle and heated plate is extremely hot. The separation tool to remove items from printer is sharp. Teachers should caution students to look but not touch and should wear heat-resistant gloves when removing items from printer.
- The melted plastic in the printer produces fumes. Printers should be used in a well-ventilated area.

group that they would like to see included in the final product. This enabled there to be one final design that would be printed in three dimensions. With Mr. Smith as CEO, the company was reorganized into different departments and students were allowed to choose their group of interest from the following departments: challenge managers, rapid reporter/public relations, chief architects, and testing coordinator/quality control.

Week 6: Finalizing the Design

The challenge managers department began creating the final design in Tinkercad (Figure 4), attending to elements needed for mobility such as moveable and articulated fingers as well as durability to press keyboard buttons. The rapid reporter/public relations department tweeted and blogged about the experience on the class web page, added photos and descriptions of the project to the classroom web page, and were responsible for knowing all details of the project such as the current stage of production or problems being trouble-shooted. Rapid reporters also managed the classroom DIY.org account in which students earn classroom badges for design-related innovations, identifying an opportunity to earn the Rapid Prototyper badge (see Internet Resources). The chief architects department coordinated building for the team (putting the prosthetic together), made design decisions during building (i.e., how pieces should connect, what pieces were necessary), ensured the team was building safely at all times, and requested additional building help from classmates if needed or guidance from the company CEO, Mr. Smith. The testing coordinator/quality control department coordinated the tests needed to check success for the company, created a standard by which the final product would be judged (i.e., functionality, durability, aesthetics), and requested additional time if needed.

The actual 3D printing of the prosthetic was completed during school hours; however, printing did not warrant the use of instructional time. Printing is time consuming. Teachers should focus students' time in the classroom on design and redesign, visualization, and simulation. Printing can be completed overnight, but if done during class time there are some safety precautions (Figure 5). The students' creation, with its flexible fingers and attachable design, was useable by the student, enabling her to simultaneously touch the sides of the keyboard with ease.

STEAM Town Hall

In an effort to stay connected to the overall purpose of the project and provide formative feedback, Mr. Smith held a daily STEAM town hall meeting at the beginning of each day. During this time, students reflected on the previous class session's work, established learning objectives and guidelines, reviewed essential questions, and were introduced to a college or career focus that related to the project (e.g., biomedical engineering). STEAM Townhall set the tone daily for rigorous and purposeful engineering work. The structure of each class session was essentially 10 minutes for the meeting, 40 minutes of teamwork, and 10 minutes for cleanup and debriefing using exit slips (Figure 6).

Conclusion

This project-based unit provided a memorable learning experience for Mr. Smith's class of devoted and motivated fourth graders. Moreover, this STEAM experience modeled interdisciplinary learning that is authentic, real-life, and which addresses a local need while simultaneously addressing standards found in the *NGSS* and CCSSO (2010) for Mathematics and Standards for Technology Literacy. Students were engaged as a class, felt like an integral part of the important mission with which they were tasked, and looked forward to their time each day in the STEAM lab. We are hopeful this article inspires other classroom teachers to seek timely and authentic learning opportunities for their students that integrate STEAM content areas and create lasting learning memories. ■

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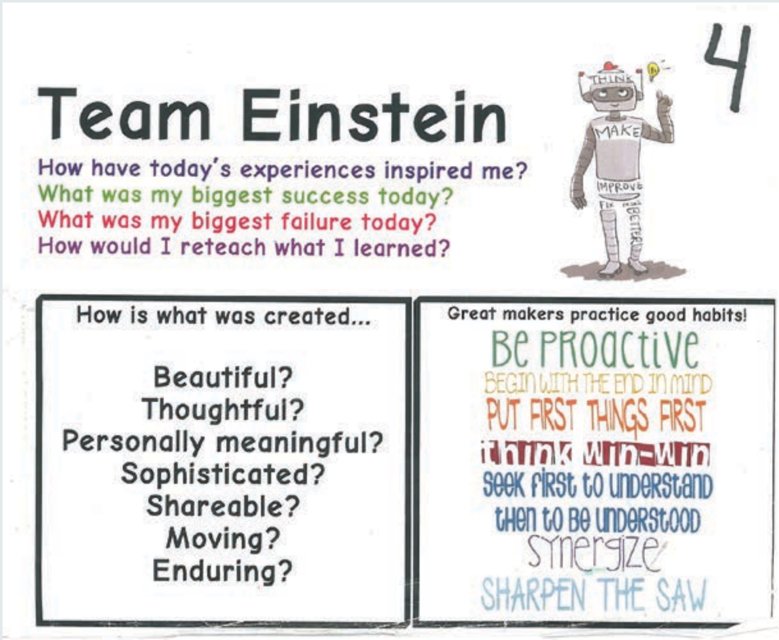
FIGURE 6.

Exit slip.



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International Technology Education Association (ITEA). 2007. *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

Martinez, S., and G. Stager. 2013. Invent to learn: Making, tinkering, and engineering in the classroom. Torrance, CA: Constructing Modern Knowledge Press.

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.

Internet Resources

Americans with Disabilities Act
www2.ed.gov/about/offices/list/ocr/docs/hq9805.html
http://bie.org/objects/cat/rubrics

Do it Yourself (DIY)
https://diy.org/

EiE: No Bones About It: Designing Knee Braces
www.eie.org/eie-curriculum/curriculum-units/no-bones-about-it-designing-knee-braces

Tinkercad
www.tinkercad.com

Tinkercad Instructions
www.3dvinci.net/PDFs/GettingStartedInTinkercad.pdf

NSTA Connection

Download Accessibility Analysis and Evaluation form at *www.nsta.org/SC1512.*

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

3-5-ETS1 Engineering Design

www.nextgenscience.org/3-5-ets1-1-engineering-design

4-LS1 From Molecules to Organisms: Structures and Processes

www.nextgenscience.org/4ls1-molecules-organisms-structures-processes

The materials/lessons/activities outlined in this article are just one step toward reaching the Performance Expectations listed below. Additional supporting materials/lessons/activities will be required.

Performance Expectations	**Connections to Classroom Activity** *Students:*
3-5-ETS1-1 Define a simple design problem reflecting a need or want that includes criteria for success and constraints on materials, time, or cost. 3-5-ETS1-2 Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the project.	• are presented with a problem concerning a need for a prosthetic hand capable of accomplishing specific tasks. A budget is provided that restricts the materials available for development. • work in teams to create designs that address the problem and then select one for the creation of the product based on how successfully it functions.
Science and Engineering Practice	
Constructing Explanations and Designing Solutions	• generate multiple solutions to the problem. • explain how their design meets the criteria constraints of the design problem. • determine a final product solution.
Disciplinary Core Ideas	
ETS1.A Defining and Delimiting Design Solutions Possible solutions to a problem are limited by available materials and resources (constraints). • The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. ETS1.B Developing Possible Solutions • Research on a problem should be carried out before beginning to design a solution. 4-LS1.A Structure and Function • Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction.	• work in teams to create designs that address the problem and then select one for the creation of the product based on how well each one meets the specified criteria for success. • investigate problems confronted by those with one hand, how to solve problems, and tools involved. • research the skeletal and muscular systems and the ways in which humans use their hands.
Crosscutting Concepts	
Systems and System Models Cause and Effect	• research and design a prosthetic body part that mirrors animal species' abilities to interact with their environment. • determine the best prosthetic design based on proficiency at completing routine tasks.