

# The new standard in technology education: 3-D design class

by Andrew Gillen

Coming up with unique and engaging ways to teach the engineering design process to middle school students is a challenging task. Three-dimensional printing is one way that you can involve your students in the design process while teaching them a completely new skillset within the modeling software.

## How to get started in 3-D design

Establishing a 3-D design class to supplement traditional technology education is not as difficult as it seems. Teachers can become proficient in a 3-D modeling program through online tutorials and lessons. Much of this software is available for free, and there are several classroom-tested software downloads from which to choose. For example, Autodesk 123D Design is free to download, and their website provides online video tutorials for learning how to use the software (see Resources). It is important that there are enough computers for each student to work independently. There are opportunities for peer review or group work during the class, but the majority of classroom activities require students to be working at their own computers. Students should also have access to a cloud system where they can upload their work to an online portfolio and where the instructor can post screenshots and assignment information.

It is important to note that schools do not necessarily have to purchase a 3-D printer in order to realize the benefits of integrating 3-D modeling and printing in the classroom. The technology is becoming more accessible and can be found in places such as libraries and “Maker Spaces.” (These spaces are areas in the community open to the public that are specifically designed to provide an open format for children and adolescents to explore science and engineering through tinkering and hands-on activities. They may be found in a museum, library, community center, or even a local college.) If schools do wish to purchase their own 3-D printer, there are several ways to finance the purchase. For example, the printer can be rented to stu-

dent families or members of the school community. Schools can also charge for teacher workshops on integrating the technology into other lessons.

This curriculum was designed for a half-year course that met once a week, but it could also be successfully implemented given a shorter timeline (Figure 1). This is an excellent opportunity for science teachers to collaborate with technical education teachers. It is the longterm goal of a course such as this that students be able to translate the skills in 3-D modeling and design to applicable science-related tasks.

## Introduction to 3-D modeling: Toy building bricks

### Overview

A good way to ease students into modeling is to start with the most basic concept: translating two-dimensional (2-D) sketches into 3-D objects. This sample activity uses toy building bricks (e.g., Legos, etc.) as an introduction to 3-D design. The hands-on activity makes for more accessible subject matter and clarifies the relationship between 2-D sketching and 3-D visualization in 3-D modeling.

### Objectives

Introduce students to the connection between 2-D sketching and 3-D modeling. By the end of the class, students should be able to translate 2-D (orthographic) views of a 3-D model in order to construct the real-life 3-D structure.

### Materials and procedure

For this lesson, you will need the orthographic projections of two different brick structures of varying difficulty and a container of identical toy brick pieces. *Orthographic projections* present 2-D views of a 3-D object at 90° angles to one another. Each view is a projection of a particular face (side) of the object. The or-

thographic projections shown in Figure 2 were created using a 3-D modeling program, but they can also be drawn by hand.

Explain the concept of orthographic projections and discuss it as a class. A good way to do this is to take a photo of a common household object at a 45° angle and then take several photos of the same object, but in only one plane of view at a time (i.e., you would photograph just the top, sides, and front of the object separately as if it were a 2-D scan). Distribute the toy bricks and ask students to assemble the 3-D brick structure from the 2-D projections shown on the board. Give no other instructions and allow students to explore the connection between the orthographic projections and the toy bricks in their hands. Give students approximately 25 minutes to complete this activity. Figure 3 depicts students engaging in this activity.

It is likely that a few students will struggle to construct the structures. Draw their attention to the simpler structure without indicating that it is a simpler structure. If the student is still having difficulties, emphasize that this is a challenging activity for most people and give a hint if necessary, such as telling the student to focus on only one view at a time.

### **Differentiation and assessment**

Throughout the activity, students will build 3-D visualization skills through verbal instruction and through the hands-on activity. Students with weaker 3-D visualization skills may choose to construct the simpler of the two brick structures offered.

Assessment should be based on individual participation, class discussions, and the student's understanding of the separation between 2-D and 3-D space. Observe students' nonverbal and verbal cues during the activity and complete a skills checklist for each student. See the online supplements at [www.nsta.org/middleschool/connections.aspx](http://www.nsta.org/middleschool/connections.aspx) for an example skills checklist that was used to assess students in this course.

### **Building basic modeling skills**

During the first few weeks, the focus should be on setting a solid foundation in the basics of 3-D modeling. Cover the coordinate system in 3-D modeling by drawing on knowledge from students' mathematics curriculum. A 3-D modeling software uses not only an  $x$  and  $y$  axis, but also a third axis that gives depth to students' objects. Allow several minutes for students to explore the program and use their intuition to discover how to

**FIGURE 1**

### **Curriculum outline**

#### **Week 1: Introductions**

- Coordinate Systems
- Navigating 2-D and 3-D space
- Real-world applications of 3-D modeling

#### **Week 2–3: Building basic modeling skills**

- Creating a sketch in 2-D space
- Drawing tools: polyline, spline, two-point-arc, three-point-arc, fillet, trim, extend
- 3-D tools: extrusion
- Additive versus subtractive modeling in engineering
- Modeling with precise dimensions

#### **Week 4: Building advanced modeling skills**

- Drawing tools: pattern, mirror, offset
- Projecting the geometry of a sketch
- 3-D tools: sweep, revolve, loft, fillet, and chamfer
- Construction line techniques
- Automatic versus manual constraining
- Importance of constraining in engineering
- Modeling to precise dimensions

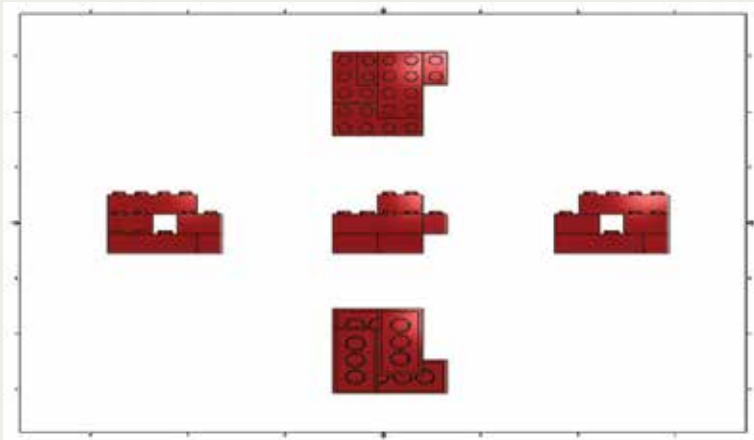
#### **Week 5–6: Mini-project**

- Introduce the Engineering Design Process
- Sketching by hand
- Part assembly (assembly constraining)
- Modeling a real-life object

#### **Week 7–12: Independent design project**

- Applying modeling to a real-world problem
- Mini-lessons: Unique tools (shell, emboss, using work planes)
- The Engineering Design Process
- Using an engineering notebook
- Creating a decision matrix
- Sketching by hand
- 3-D printing techniques and 3-D printer function

**FIGURE 2** Orthographic projections of toy building bricks



use the mouse to navigate the model space. Demonstrate key aspects of mouse navigation, such as how to use the scroll wheel and the difference between left- and right-clicking in the program to supplement what they have learned on their own. Once this is done, the first sketching tools can be introduced. We started with ba-

**FIGURE 3** Student comparing orthographic projections to physical toy bricks



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sic drawing tools and simple shapes. After students have demonstrated the ability to successfully use the basic drawing tools, the first 3-D tool introduced should be the extrusion tool. This tool allows the user to add depth in one direction from a 2-D profile. Figure 4 is an example model for the challenge activity for the lesson on the extrusion tool. It was also helpful to create “cheat sheets” for students for certain tools, as in Figure 5.

### Building advanced modeling skills

Once students gain a skillset in the basic tools at their disposal, begin to introduce more advanced modeling techniques. Start with sketch manipulation tools such as pattern, mirror, project geometry, and offset, which allow the

student to use an existing sketch to achieve a desired design. Students should now also be ready for more advanced 3-D tools that require two or more steps to complete. Again, instructor-prepared example models should be given so students can practice their new skills so the instructor can assess students’ progress using a skills checklist (see the online supplements). Figure 6 shows an example model and practice dimensions for more advanced 3-D tools.

### Mini-project

In our class, we decided to have students complete two different projects. The first we dubbed a mini-project because the scope was smaller than the culminating independent design project. The mini-project also provided the opportunity for us to introduce the engineering design process and sketching techniques that students would need for the culminating independent project. Students designed and built puzzles out of wooden blocks and then modeled the puzzles on the computer. Pine wood blocks (1/2 inch square or larger) can be obtained from most hobby and craft stores. This project was adapted from the puzzle cube project within the Introduction to Engineering Design course from the PLTW Engineering program (Project Lead The Way, Inc. 2015). Throughout this process, students applied some of the modeling tools they learned, such as the 2-D sketching tools, the extrusion 3-D tool, and the constraining assembly tools. During the mini-project,

students use orthographic (2-D) and isometric (3-D) sketching on regular graph paper and isometric paper (60° triangular graph paper), respectively. Additionally, students practiced the skill of creating an assembly file in the modeling program and using assembly constraints. An *assembly file* combines all the separate model part files to form a complete design. In professional modeling programs, this is a specific file type, but in free modeling software it can simply be a designated part file. In the assembly file, students use the constraint tools of the program (i.e., mate, flush, insert, snap) to assemble the parts that make up the complete design. Not every creation requires multiple parts and an assembly file, but it is an important skill necessary to complete more complicated multi-part 3-D designs. Note that although an assembly file is great for demonstration and planning, each part in the assembly would have to be separately 3-D printed. This project was assessed using a rubric (see the online supplements) that focused on sketching techniques on paper and modeling requirements in the program.

## Culminating project

For the independent design project, it was important that students explicitly worked through the engineering design process. The following outline shows the progression of the project based on a simplified engineering design process.

1. *Assess a need/define a problem:* Individually or in pairs, students consider problems that affect their lives. As a class, students compile a list of potential problems to solve. Make sure the list is large enough that there are enough options for each student to choose a topic.
2. *Research/brainstorm ideas:* With guidance from the instructor, students select the problem that they wish to solve with their invention. Students then begin to sketch and brainstorm possible solutions in their engineering notebooks. On the computers, students research their selected problem and current solutions (if any exist), as well as any science and engineering principles relevant to their project.
3. *Choose a solution:* Students draft a decision matrix to select the best solution from their brainstorming and then conference with the instructor. A decision matrix is an organized chart to determine the best solutions based on the design require-

FIGURE 4

Example challenge activity  
(extrusion tool)

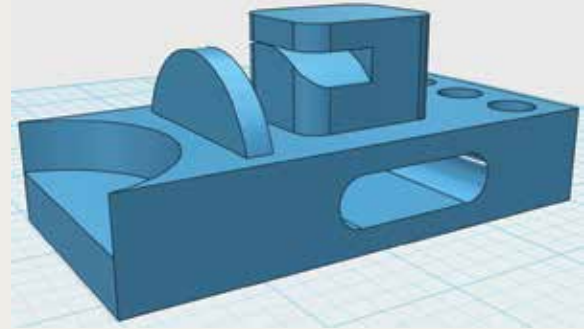
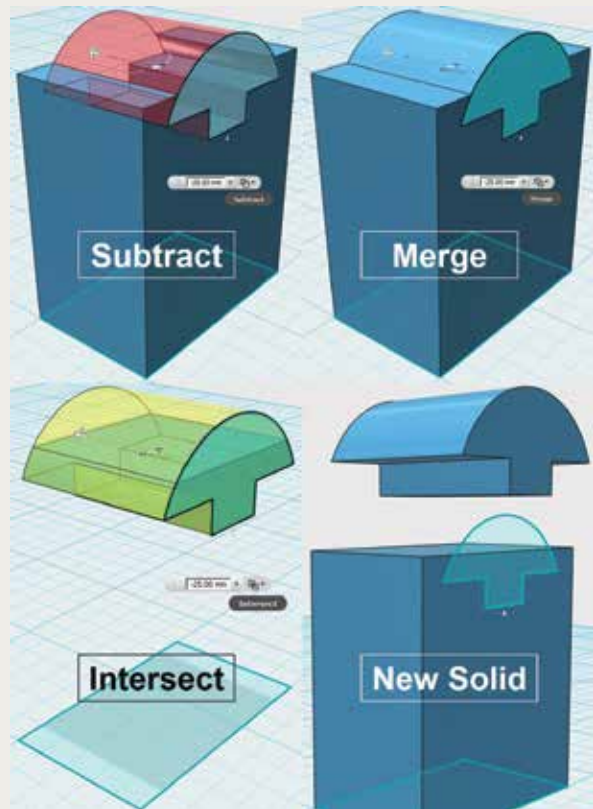


FIGURE 5

Cheat sheet example  
(extrusion tool)



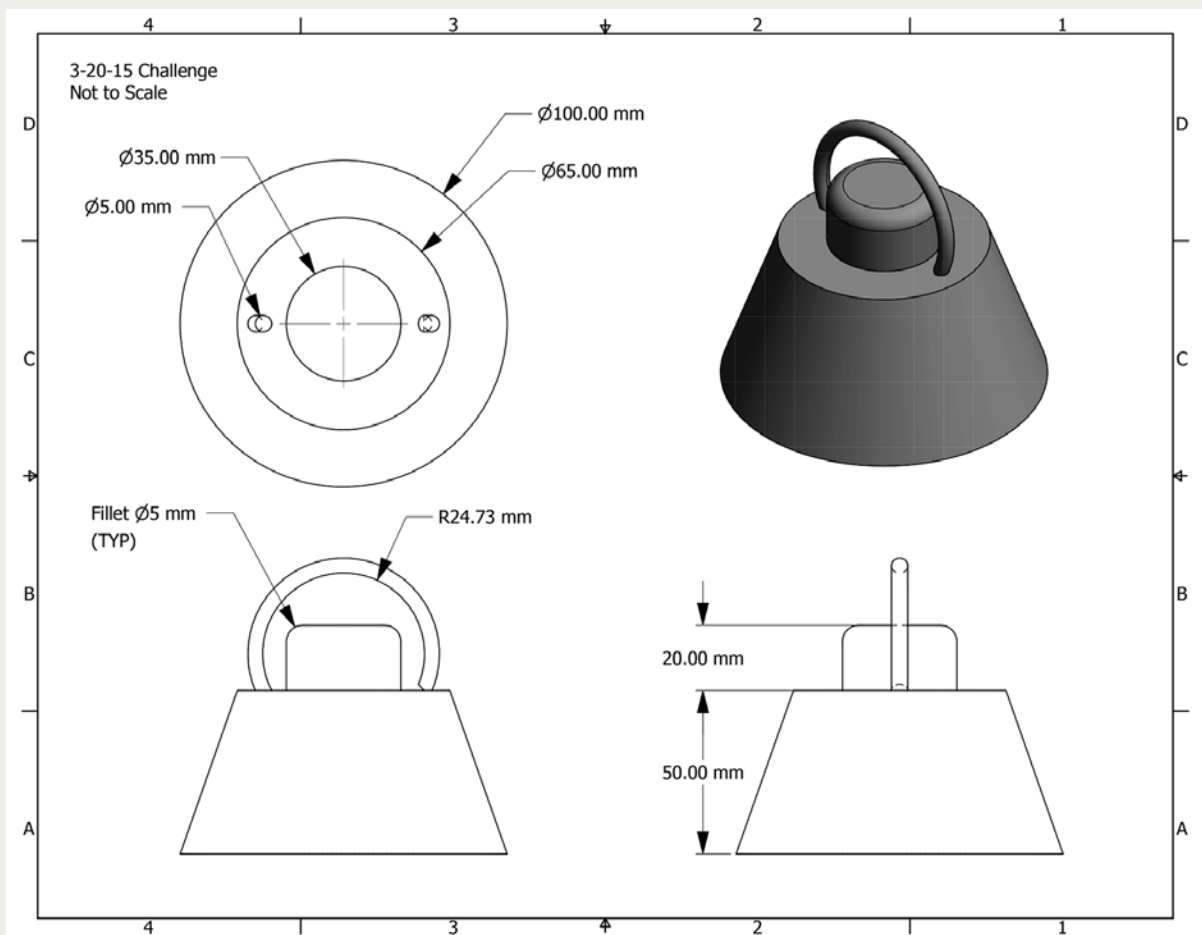
ments. The class should go through the process of making a decision matrix as a group.

4. *Model and print:* Students model their designs on the computer and print them on the 3-D printer.
5. *Test/rebuild:* Students test and analyze their design and make modifications based on these results. For example, a student who designs a new type of guitar pick might allow other classmates to use it and rate aspects of the design on a scale. Any test results or modifications are recorded in their engineering notebooks. The engineering notebooks are assessed for completeness only. They serve as a means to introduce students to

the importance of good engineering practice in recording work performed. Look for annotated sketches, tables, and bulleted lists, and check that every entry is clearly dated.

6. *Communicate the solution:* Students draw isometric (3-D) and orthographic (2-D) sketches that are annotated and dimensioned. These are used as a visual aid, along with the computer model, as each student presents his or her design to classmates. Sketching by hand was challenging for many students. To facilitate the process, we set up a sketching station in the classroom that supplied students with everything they needed to

**FIGURE 6** Example challenge activity (modeling with precise dimensions)

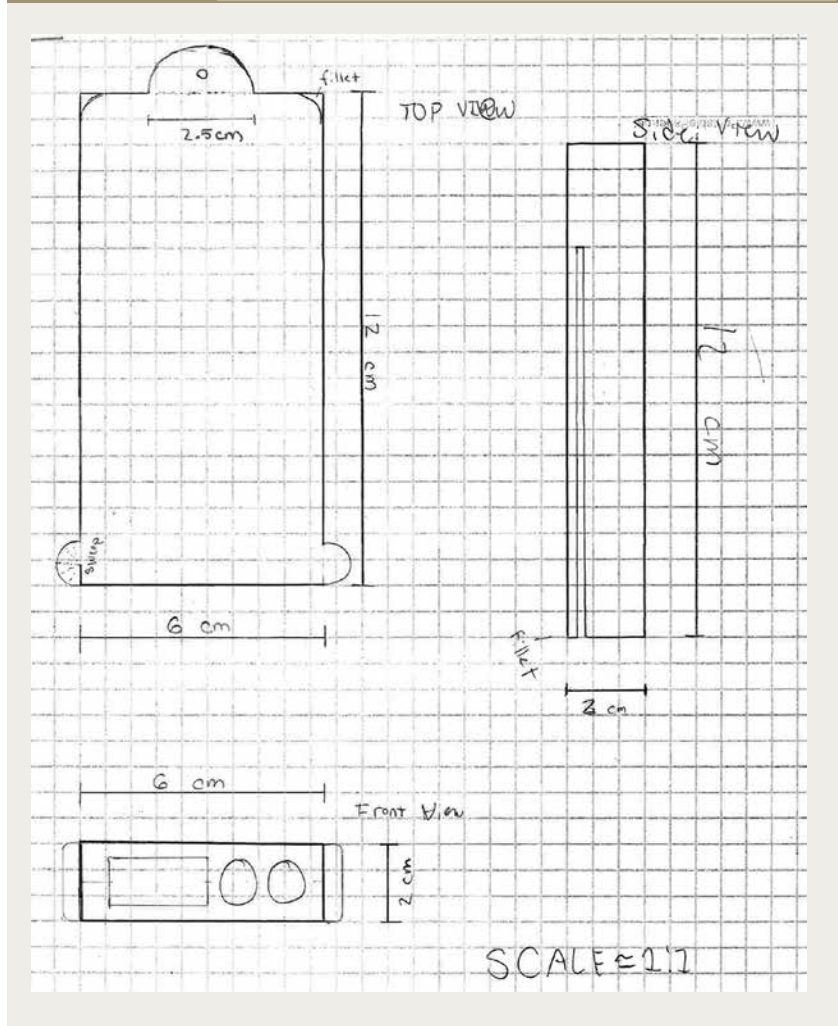


create their sketch. This station included a sketching folder for each student, rulers, pencils, graph paper, isometric paper, a “cheat sheet” of line types. The graph and isometric paper can be printed onto regular computer paper using online templates. Some students used their printed models to sketch and others used the model on the computer screen. Figure 7 is an excellent example of an orthographic sketch created by a student for a novel backpack organizer.

For the independent design project, all students met a set of minimal requirements, but there were no maximal boundaries for the scope of the student’s project beyond the time constraint of the class. As a result, the difficulty of each student’s design project was matched with that student’s individual ambition and abilities. Students were encouraged to design a sufficiently complicated project to suit their individual skillset (based on assessment from previous activities). Students who needed more guidance and instructor intervention were given the opportunity to have additional class time to work on the project. The project was assessed using a rubric (see the online supplements).

**FIGURE 7**

**Student example sketch from culminating project**



## Assessments/evaluations

The toy brick sample activity served as a preassessment for gauging the 3-D visualization skills of each student. At the end of the class, students participated in a similar activity with new orthographic projections of a toy brick structure. Anecdotally, students seemed much more comfortable participating in this activity at the end of the class. The majority of the students finished in half the time of the original activity, and some students even asked for another structure challenge to complete.

Throughout the semester, I completed a skills checklist based on observation during the practice ac-

tivities (see the online supplements for an example of a skills checklist). Instruction was tweaked along the way based on the skills checklists from each week. Beyond observation during class time, I reviewed files uploaded to the student’s online portfolio and the engineering notebooks or folders kept by students during the projects.

Students were walked through each item in the rubric (see the online supplements) and assessed in three main ways:

1. Sketching techniques: Was the sketching neat

and were the lines accurate? Were lines drawn with a ruler or were they feathered? Did the student use pencil or pen? Was color used to enhance the sketches or did it use detract from the clarity of the sketches? Was scale indicated on the sketch and were objects drawn in correct proportion to one another?

2. Modeling tools: Did the model meet the design requirements outlined in the assignment? Did the student use a variety of relevant and appropriate tools to create their design?
3. Creativity and effort: Was the student on task during the available class time? Was the application to a real-world problem adequate and was the solution practical? Was the invention unique and did it solve the defined problem in a creative way? Was the student able to identify a relevant step in the engineering design process as it pertained to their current phase in the project?

## Differentiation

Students were able to learn the tools for a given lesson through verbal instruction and through the hands-on practice activity. All challenge activities that accompanied the modeling lessons were differentiated. I did this by providing two practice activities of varying difficulty and one challenge activity that used concepts from the next week's lesson. In this way, students with weaker 3-D visualization skills had the option to complete the simpler practice activity and students who had progressed beyond the content of that week's lesson could work on the challenge activity. The distinguishing factor between the simpler and more complex practice activity is that the challenge activity included more complex geometry. Nearly all of the lessons leading up to the projects were conducted in this manner.

## Example connections to science lessons

There are many different approaches that a middle school science educator could take to integrate 3-D modeling into the classroom. The two distinct examples shown below demonstrate how 3-D modeling and printing might be integrated into the science classroom.

### Example 1: Thermal energy transfer

The principles of engineering design and the objectives of the 3-D modeling lessons can be tied to the

*Next Generation Science Standards (NGSS)* performance expectation MS-PS3-3 Energy (NGSS Lead States 2013). Students would be required to directly consider shape and relative function in their design of a custom device to maximize or minimize thermal energy transfer. This could be a deliberately shaped solar cooker, but it could also be a model of a thermally efficient room or building. Having the ability to make complex shapes and curves in the 3-D modeling software and then to 3-D print that design and test it in its tangible form would greatly enhance the student experience and help to improve the understanding of scientific principles such as conduction and convection.

### Example 2: Molecular structures

3-D design and printing could be connected with MS-PS1-1 Matter and its Interactions. Students could model and print the molecules as a whole or design them in individual atoms of accurate relative size to be assembled after printing. Students would be required to design deliberately, modeling the correct number of atoms in the correct relative scale and arrangement.

## Conclusion

In order to benefit from 3-D printing technology in the classroom, students need to build a skillset in 3-D modeling. When the technology class is also a modeling class, teachers from other disciplines can integrate the skills students have acquired into their lessons to enhance learning in math, engineering, and science. We often said to our students that there are a dozen ways to model the same object. A given object could take five hours or five minutes to model. The point was that we weren't just teaching them what different tools can do but also how to use those tools situationally, depending on what the student wanted to model. With a skillset built on that foundation, students will be ready to use modeling to enhance their learning in other academic areas. The benefits from cross-curriculum opportunities are many. The mathematics teacher might use the students' 3-D modeling skillset to enhance a geometry lesson. The science teacher could offer students the option of modeling and 3-D printing the parts of a cell to gain a better understanding of the connection between structure and function in cell theory. We found that students in our course wanted more integration like this. Each stu-

dent completed an exit survey and gave their overall impression of the class material. More than one student identified modeling as a life skill they were glad to have learned, and many noted possible applications to other disciplines such as structural engineering. By far, the most frequent request was for more opportunities to use the 3-D printing technology in school. ■

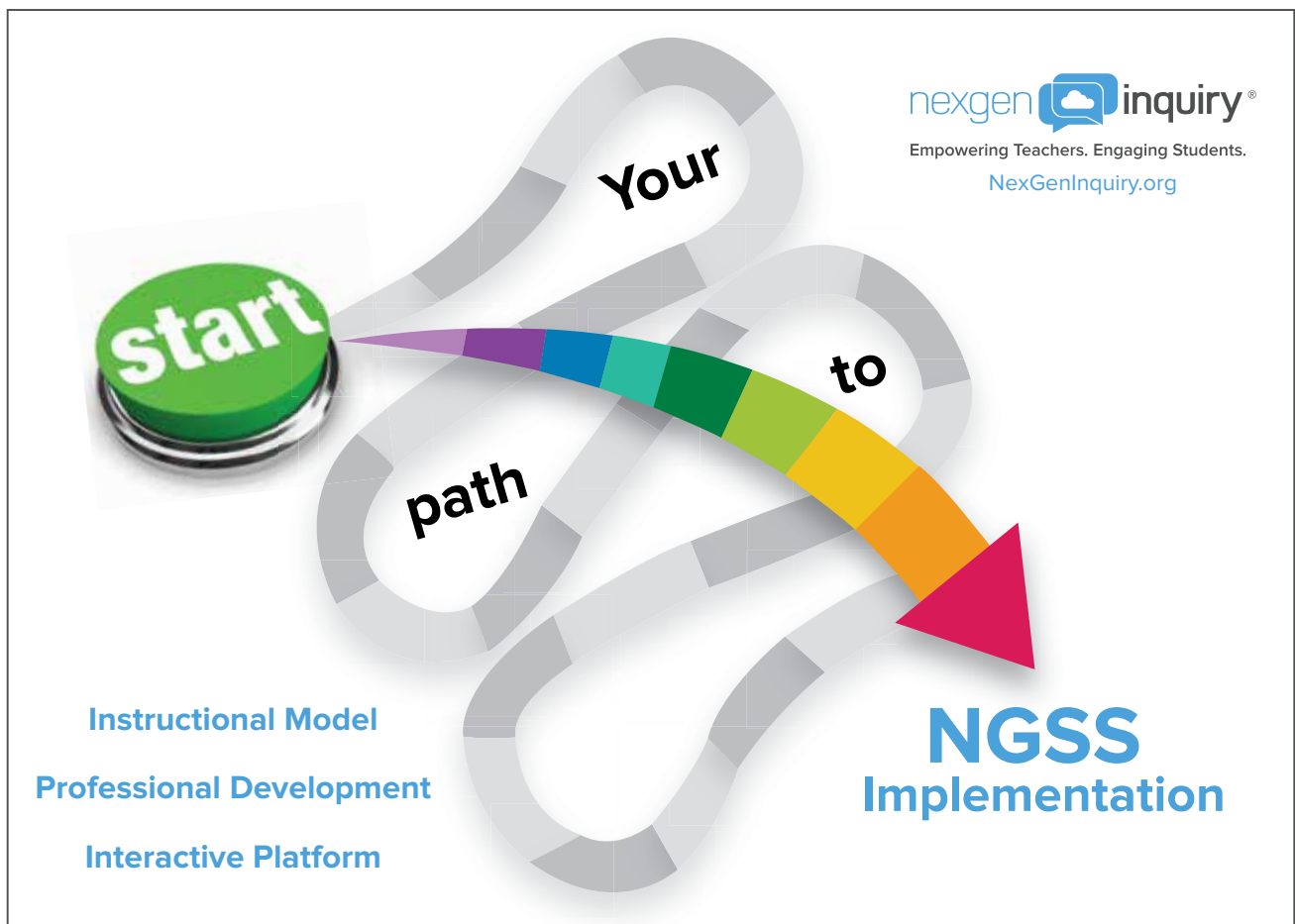
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- NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. [www.nextgenscience.org/next-generation-science-standards](http://www.nextgenscience.org/next-generation-science-standards).
- Project Lead The Way, Inc. (2015). Project 4.1 Puzzle Design Challenge. In PLTW, *Introduction to Engineering Design* (P4.1). [www.mypltw.org](http://www.mypltw.org).

## Resources

- Free 3-D modeling software options:
- AutoDesk 123D Design (Available for Windows, Mac, or iPad)—[www.123dapp.com/design](http://www.123dapp.com/design)
- Google SketchUp Make (Available for Windows or Mac)—[www.sketchup.com](http://www.sketchup.com)

**Andrew Gillen** ([andrewlukegillen@gmail.com](mailto:andrewlukegillen@gmail.com)) will be attending Virginia Polytechnic Institute and State University to pursue a PhD in Engineering Education. As a teaching intern at the Talcott Mountain Academy in Avon, Connecticut, he designed and implemented a course in 3-D modeling.





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