IDEAS *for secondary instruction*

A Mindful Introduction to 3D Printing

Teaching Students to Maximize Output while Minimizing Waste.

BY GREG J. STRIMEL, DTE AND MILO ENGEL

Introduction

This article showcases a lesson developed by the authors to be a mindful and engaging introduction to 3D printing that positions students to maximize the output of the 3D-printing process by reducing print failures and inefficiencies. The big idea for this lesson is to have students learn and apply the concepts behind designing for manufacturability through the additive manufacturing process. To do so, students will explore various 3D-printed designs and consider the concepts of what makes those designs good or bad. These concepts include print orientation, infill, layer height, and support. Students will then be challenged to apply their acquired knowledge by engaging in an engineering challenge to optimize the speed, quality, and efficiency of a 3D-printed product by appropriately adjusting print settings within slicing software—helping to ensure that students know how to take care in printing objects in a way that maximizes the output of the printing process while minimizing the waste of materials and other resources. At the end of the challenge, students will evaluate and share both the print settings and the final features of the printed products to illustrate and reaffirm their knowledge from the lesson as well as determine which student team achieved the most ideal results for the challenge.

Lesson Context

Our lives are entwined with the concept of efficiency. How can I maximize miles per gallon or dollars per day of food? Every corner of our lives holds these balances. In this lesson, students are confronted with a new form of this efficiency. This lesson introduces a form of creation that brings paper printing into the third dimension. With 3D printing, virtual objects are brought to our hands and can be shared with the rest of the world. Such a concept has become normalized for many of us but can be the seed of creation for students. These manufacturing processes have improved in terms of time, resources, creativity, and collaboration between several industries such as with toys, vehicles, and biomechanical components. However, with 3D printing, there are still several critical factors (tolerances of the printer, cost of filament, time to print) to consider during both the design and manufacturing process that could heavily constrain the printer's ability to function properly. These factors for consideration are typically unknown for many new users, leading to the use of excess materials and other resources through trial and error with the design, slicing, and printing processes. This waste of resources can especially be true within engineering technology classrooms that often rely heavily on the use of 3D printers for class projects.

However, in the lesson detailed in Tables 1 and 2, the manipulation of these factors is about to be put to the test. The lesson centers around an engineering challenge that involves an off-road vehicle manufacturer requesting support in the additive manufacturing process. In 2020, during the COVID-19 pandemic, a Canadian woman named Allison Parliament left a note on a stranger's Jeep that read "Nice Jeep." With the note, she included a small yellow rubber duck. This act went viral and today "ducking" Jeeps has become a universally accepted symbol of appreciation within the Jeep community. The off-road vehicle manufacturers want to encourage this trend by providing a unique 3D-printed duck with each vehicle sold. However, before they start, they want to know how long a duck will take to print, how good the quality will be, and how unique they can be. The manufacturer needs the class to provide them with a 3D-printed duck sample that takes less than 14 minutes per duck to print, but still resembles a duck. The lesson will use this context to learn about designing for additive manufacturing, slicing, and print settings to adhere to desired constraints before sending files to the 3D printer. This mindful approach is what students are encouraged to use in any future 3D printing ventures in the classroom and beyond—hopefully then minimizing the plastic and energy wasted and enhancing the efficiency of the printing process.

Table 1. Lesson Overview

Lesson Purpose: The purpose of this lesson is to help students understand how to slice an object to prepare it for 3D printing. However, beyond this is the purpose of having students understand the process to optimize a product design to use the least amount of raw materials while also taking the minimal amount of time.
ENGINEERING CONCEPTS (Framework for P-12 Engineering Learning, 2020) • **Design Communication -** articulating their ideas, decisions, and information during and at the conclusion of a design project, while considering the target audience through a variety of verbal and visual communication strategies and tools. • **Manufacturing -** designing a product in such a way that it is easy to produce and then making the product by applying appropriate manufacturing processes. • **Modeling and Simulation -** using a variety of models or methods to simulate, evaluate, improve, and validate design ideas.
STEM STANDARDS *Standards for Technological and Engineering Literacy* (2020) • STEL-7Y » Optimize a design by addressing desired qualities within criteria and constraints. • STEL-4R » Assess a technology that minimizes resource use and resulting waste to achieve a goal. *Next Generation Science Standards* (2013) • MS-ETS1-3 Engineering Design » Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

LEARNING OBJECTIVES

- Students will be able to explain the differences between the key components of 3D printing: orientation, infill, bed adhesions, layer height, and supports/overhangs.
- Upon analyzing failed 3D prints, students will be able to apply their knowledge on orientation, infill, bed adhesions, layer height, and supports/overhangs by recognizing which component of 3D printing was the reason for failure.
- When tasked with optimizing the speed of a 3D-printed product, students will be able to make design/printing decisions based on their knowledge of orientation, infill, bed adhesions, layer height, and supports/overhangs.

ENDURING UNDERSTANDINGS (Framework for P-12 Engineering Learning, 2020)

- Modeling and Simulation is the process of using a variety of media, both physical and digital, to determine how well a design idea will perform as well as to communicate a design idea to others. This concept is important as modeling and simulating actual events, products, structures, or conditions through mathematical, physical, and graphical/computer models helps engineering professionals predict the effectiveness of their solutions prior to producing a prototype, which can save valuable resources (time, materials, money, etc.).
- Manufacturing is the process of using technology to transform resources into valuable products. This requires knowledge related to (a) design for manufacturability, (b) additive manufacturing processes, and (c) subtractive manufacturing methods, which are important as the design of products is affected by factors that are specific to the ability to effectively manufacture the product itself.
- Design Communication is the process of effectively and efficiently sharing ideas, decisions, information, and results with team members and various stakeholders throughout the design process as well as with the intended audiences at the conclusion of a design project (which can include conveying the information necessary to describe the results of the project, produce/implement a design solution, and to use the design product). This process is important as an engineering professional's work is only as good as their ability to communicate with others.
- Attention to detail is the ability to demonstrate a thorough concern for all the areas involved in accomplishing a task, regardless of size. This ability generally allows the work being done to achieve the tasks to be more accurate and less prone to developing small errors leading to major flaws over time

DRIVING QUESTIONS FOR STUDENTS:

- How can I use my knowledge of the 3D-printing process to avoid common issues that occur while designing the products to print?
- How can I ensure that the final 3D-printed products result in their desired forms before and during the 3D-printing process, to minimize the number of deformations within the products along with the amount of resources used?

SOCIALLY/LOCALLY RELEVANT CONTEXT:

New innovations and creations in technology are allowing more households accessibility to manufacturing processes that have been otherwise entirely cost-prohibitive and kept for specialized industrial cases. Today, one of the cheapest and most obtainable examples is that of the 3D printer. A student with both the knowledge and means of 3D printing catalyzed with a mission has boundless creative potential. However, if not used in a mindful way, 3D printing can result in a lot of unnecessary waste and a lack of efficiency in the printing process. But the catalyst in this lesson is to learn about a more appropriate and efficient way to design and print products is an engineering challenge presented by an off-road vehicle manufacturing company. This company wants help to efficiently use its 3D printers to provide a "yellow duck" with every vehicle sold. The company is requesting 3D-printed duck samples that take less than 14 minutes to produce with minimal use of plastic and energy. Therefore, the students are tasked to provide the company associates with directions to 3D print the best quality duck for the least amount of printing time possible with minimal waste.

REQUIRED PRIOR KNOWLEDGE AND SKILLS

Participants in this activity are expected to have prior knowledge related to:

- General understanding of file manipulation
- Ability to download and install a program onto their computer

CAREER CONNECTIONS

Computer Graphics Design – Mechanical Engineering – Manufacturing Technician

Table 2. Engineering Design-Based Learning Lesson Plan

Engage: Sets the context for what the students will be learning in the lesson and captures their interest in the topic by making learning relevant to their lives and explanation.

Have 3D-printed puzzles (see Figures 1 and 2) on the tables so that there are 3-4 students per group. As students come into class, have a worksheet with the following items and instructions on each group's table next to their puzzle:

The objects in front of you were created via additive manufacturing, specifically, 3D printing. By the end of class, you will be able to create similar objects. They were created with a tiny nozzle that produces layers of plastic about the thickness of a sheet of paper.

1. Try to put the puzzle together. Just like a 3D printer, you must start from the bottom and build up layer by layer. Look closely at the sides of the print, you may need to hold it up to the light. What do you notice about the texture?
2. Now look inside the print, why is it not a solid object? A solid object is 100% dense, with no air inside it. An object like a water bottle is 0% dense; it is completely air. What % density would you say your print is?
3. Look even closer, if each tiny layer took an average of 185 seconds, how long did the print take? Make an educated estimate and show your logic.

Each group should make their way through these worksheet items until most of them have a good handle on the basics of 3D printing.

- The 3D-printed puzzles should be prints cut on a bandsaw. Have students try to piece them together. As students do this, have them imagine that instead of 7 pieces, they had to do 300 pieces. This is how a printer makes an object. Examples are shown in Figures 1 and 2. The goal is to have students understand the concepts behind a printer building up layers. Have a worksheet printed out for each student. They should only get 4 minutes for the entire worksheet.
- Students should be placed into groups of 3-4 and share their common findings as well as where they disagree. Finally, the class comes back together to share findings. This should afford you a good perspective of their levels of understanding of 3D printing.
- If available, keep a list of student observations to tie back into later in the lesson. If the students notice infill, be sure to connect with them in the explanation later in the lesson.
- A challenge can be given to the students to see who can build their 3D-printed puzzles the fastest (the puzzle can be difficult to assemble when no instructions or details about the final product are given)

Figure 1. Sample 3D-printed puzzle before bandsaw.

Figure 2. 3D-printed puzzle after the bandsaw.

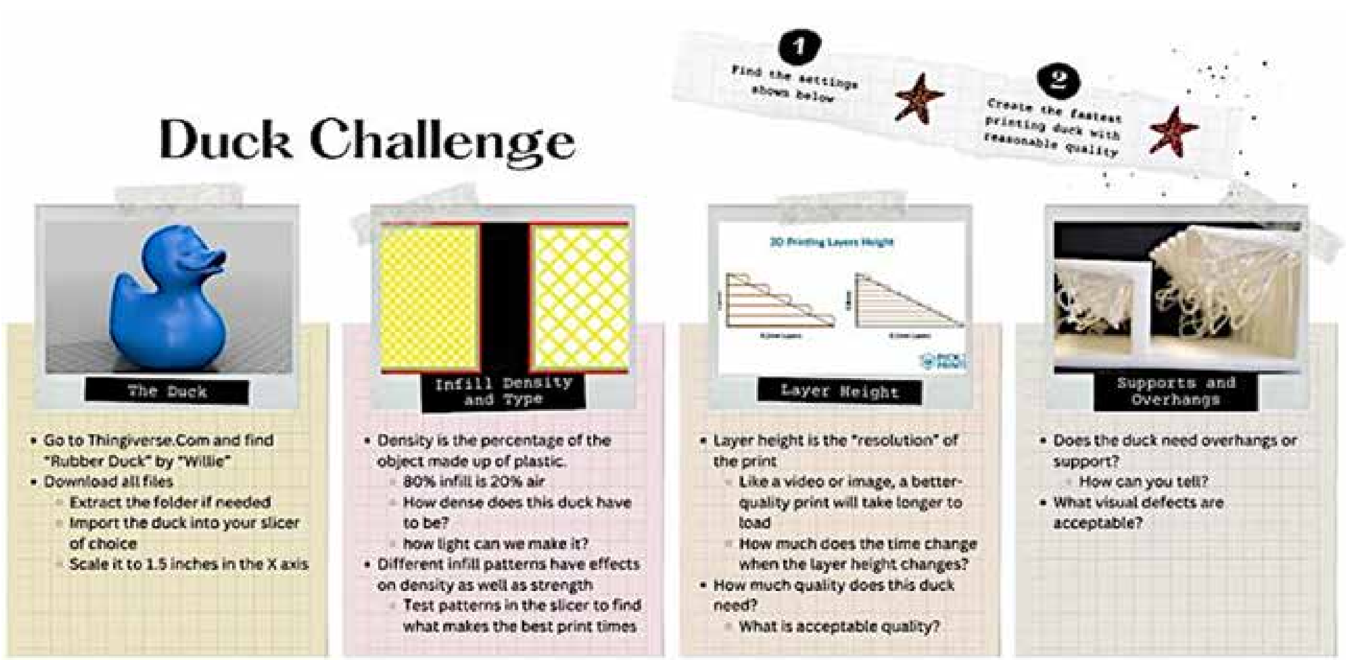
Now, introduce the concept behind manufacturing in general. Everything was at some point just an idea in someone's mind. The idea then had to be committed to a process to be created. By understanding how a 3D printer works, students will be able to create their ideas. It is important to explain the difference between additive manufacturing processes and subtractive manufacturing processes, as well as the pros and cons of both. Find examples of each in your room, if possible.

- Additive manufacturing
    - » Highly efficient and eliminates waste
    - » Faster route from design to production
    - » Create complex designs easily
- Subtractive manufacturing
    - » Applies to various materials like metal, plastic, wood, and other materials
    - » Used for all shapes like holes, cylinders, screw threads, or flat surfaces
    - » Ideal for obtaining a smooth surface
    - » Produces high accuracy with 0.0025 mm close tolerance

Now, introduce the off-road vehicle manufacturing challenge (see Figure 3). Later, students will either "slice" a duck themselves or identify features/faults of prints, depending on the instructor's approach.

Figure 3. Off-road vehicle "duck" manufacturing challenge.

An off-road vehicle manufacturing company wants help to efficiently use its 3D printers to provide a "yellow duck" with every vehicle sold. The company is requesting 3D-printed duck samples that take less than 14 minutes to produce with minimal use of plastic and energy. Therefore, you are tasked to provide the company associates with slicing directions to 3D print the best quality duck with the least amount of printing time possible and minimal waste.

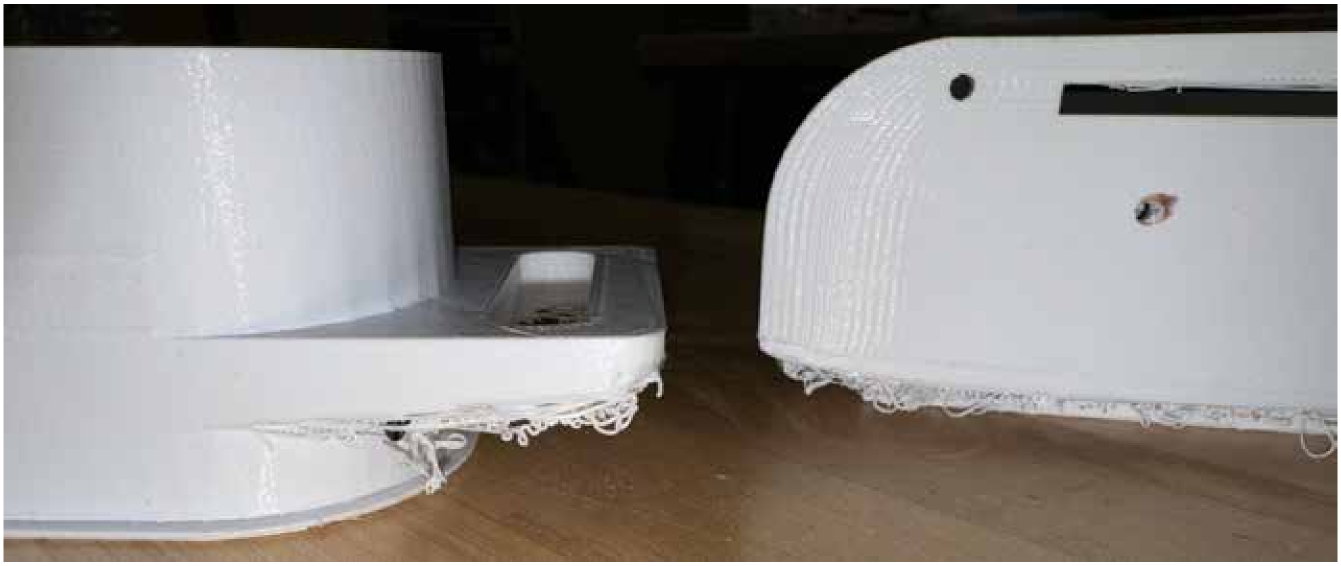


Explore: Enables students to build upon their prior knowledge while developing new understandings related to the topic through student-centered explorations.

For this portion of the lesson, use the presentation provided at: https://tinyurl.com/3DMindful

You can also show images and videos of prints failing, analyze why it is not right.

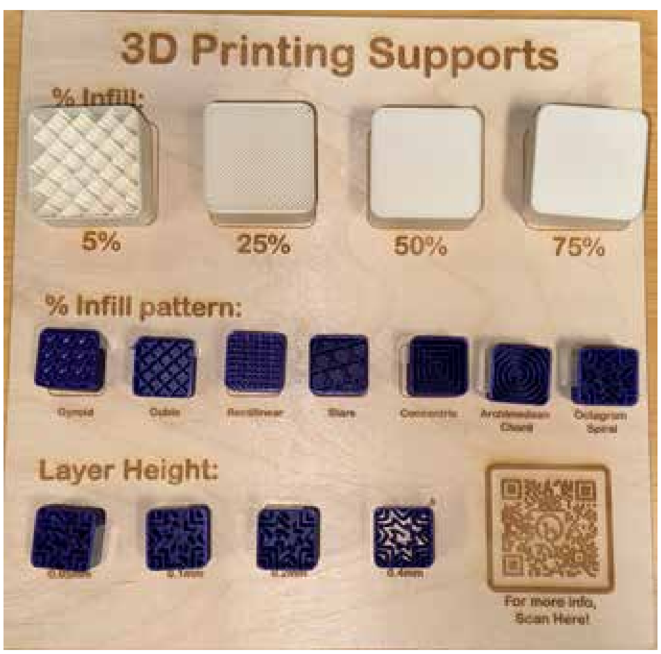
- Failing Print Video: https://tinyurl.com/3DMindful
- Failed Print Photo:



Then guide a discussion about how students would 3D print a duck:

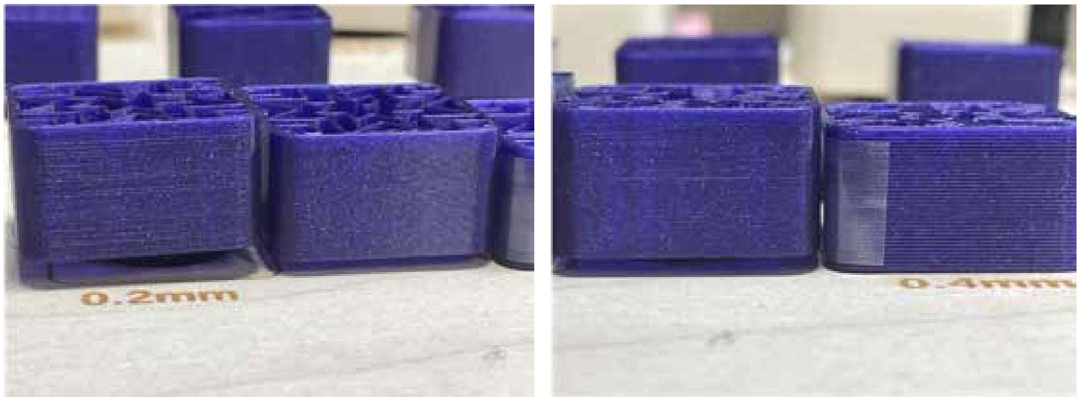
- Have a "3D-printed duck" lineup with varying infill settings; ask which is best and why? Would they rather have a really heavy pillow or a really light one? Is denser always better? (see Figure 4).

Figure 4. Different infill settings.



- Ask about layer height settings. Which is best and why? What are the time constraints? (See Figure 5)

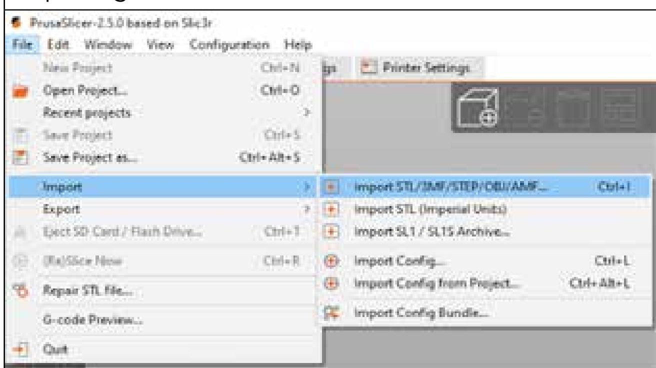
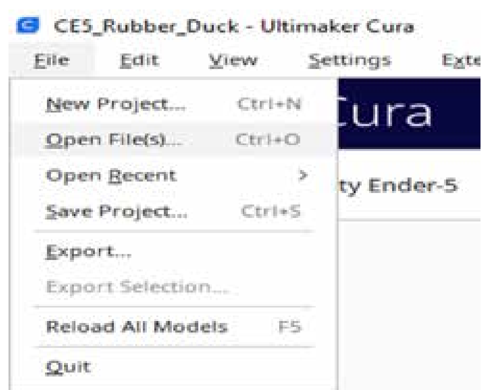
Figure 5. Layer Height Settings



- When drawing, do you always want the best quality you can possibly get? When do you not want the best quality?

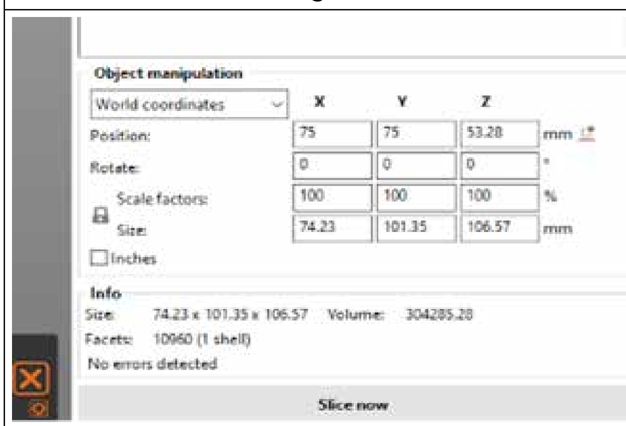
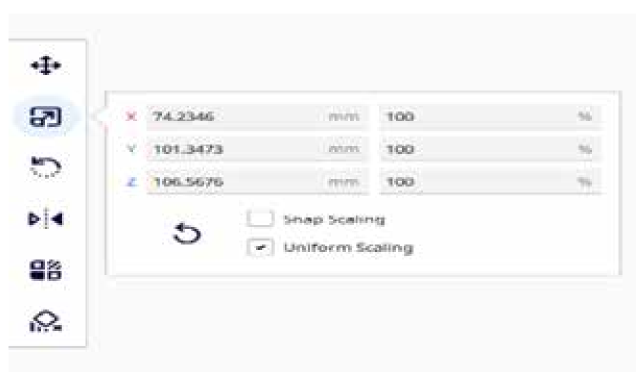
Explain: Summarizes new and prior knowledge while addressing any misconceptions the students may hold.

Guide students through the following topics related to slicing an object for 3D printing. Most slicers are very similar in their functionality. Below is an overview of printing an efficient "duck" using two common slicers, Prusa and Cura.

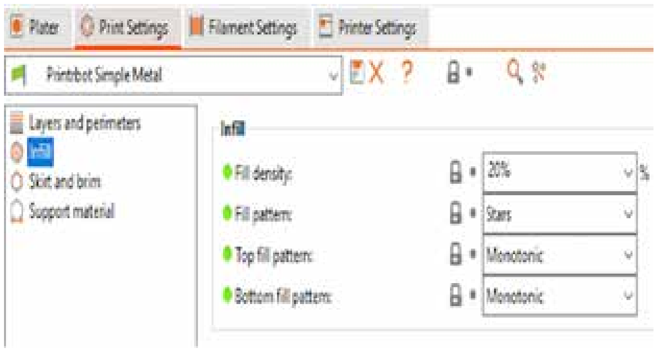
Prusa Slicer	**Cura Slicer**
Importing a duck. Have students download this file and import it into the slicer.	
	

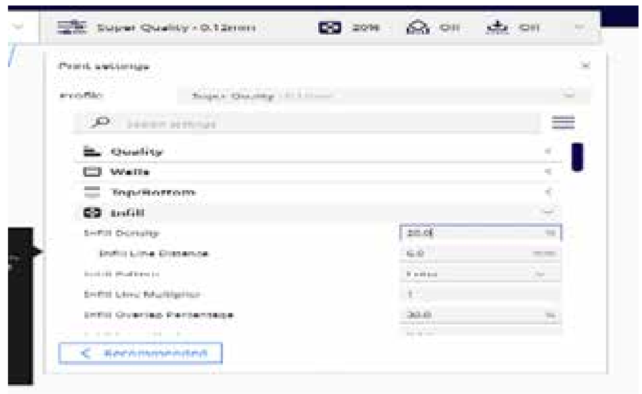
Managing the duck in the slicer: Orientation/rotation/scale.

- In either slicer, select the imported model and use the managing icons to maneuver the model.
- Have students change the Z size to 25 MM and move the model to a corner of the bed.

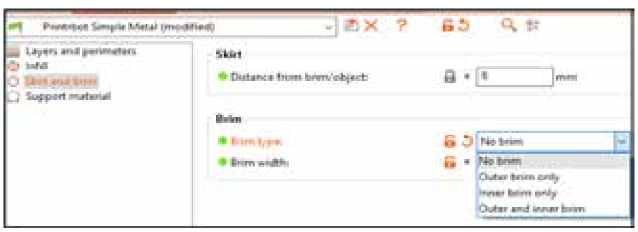
	

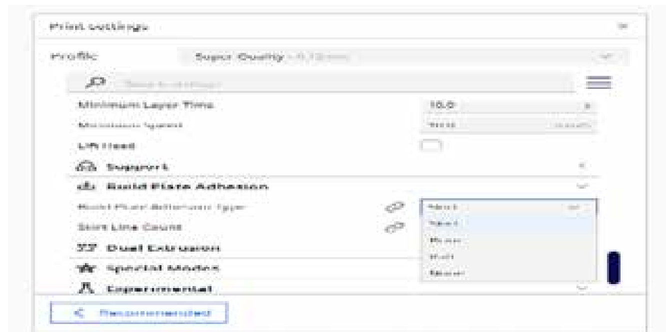
Changing the Infill. Have students recall the infill density examples in the presentation. Students can change the infill to whatever they want and test the print times.



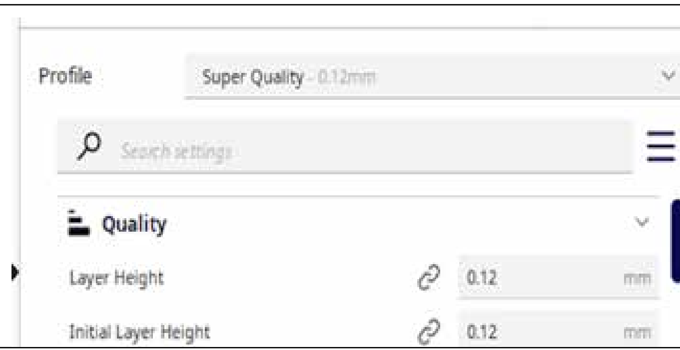


Show how to add bed adhesions. Explain that this print doesn't need a raft. But, if we were printing something tricky like a baseball, which only sits on a tiny part of a table, we would need it.

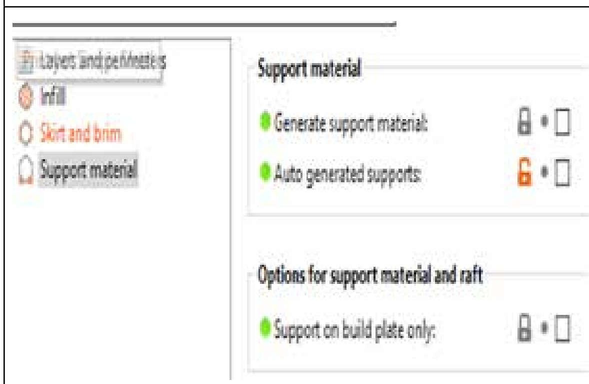


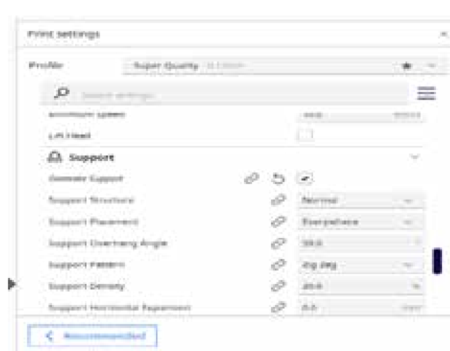


"Resolution" of print: This is a big influence on quality of, and time required for, a print. Show students how to change layer height and how this influences print times.



Supports/overhangs: Explain how something like a bowl would not need supports if it was sitting concave side up, but if you flip it over, it would need a lot of support.





Engineer: Requires students to apply their engineering knowledge and practices, as well as their engineering habits of mind, to define a problem and develop, make, evaluate, and refine a viable solution.
This section has two parts that are interchangeable depending on the level of the students. First, students are put into groups of 2-4 and given the "Maximizing Output while Minimizing Waste" worksheet (see Figure 6) to review the print settings used. Second, students will apply their learning by creating the fastest printing duck without failure (see below). **Off-road vehicle "duck" manufacturing challenge** An off-road vehicle manufacturing company wants help to efficiently use its 3D printers to provide a "yellow duck" with every vehicle sold. The company is requesting 3D-printed duck samples that take less than 14 minutes to produce with minimal use of plastic and energy. Therefore, you are tasked to provide the company associates with slicing directions to 3D print the best quality duck for the least amount of printing time possible with minimal waste.
Evaluate: Allows students to evaluate their own learning and skill development in a manner that empowers them to take the necessary steps to master the lesson content and concepts
3D print the fastest duck (or two if time permits). While these ducks print, have each group explain what they did to make printing faster and write it on the board. Discuss what worked and what did not in regard to efficiency and waste. Students should get to keep their prints.

Figure 6. Maximizing output while minimizing waste worksheet

Name__________________________________ Date_______________________ Number on bottom of 3D-printed Item ______

Describe your item with as much detail as possible. If applicable, why did it fail?

____

____

____

Compare your item to the items in the front of the classroom and to other groups' items.

What is:

The infill %___________

How do you know?

____

The layer height _________mm

How do you know?

____

The type of bed adhesion (circle one) Raft/Brim/None

How do you know?

____

Did your item need supports? (Circle one) Yes/No

Did it have them? Yes/No

How do you know?

____

Bonus question

What was your item used for?

Conclusion

By the end of this lesson students will have successfully printed a product (a duck). While the knowledge gained from this lesson is valuable in an increasing number of careers (e.g., industrial designer, mechanical engineer, manufacturing technician, or computer-aided design technician), as many workplaces make use of either additive or subtractive manufacturing. However, the more valuable lesson here is that of efficiency. In nearly every important situation a person can face, there is a balance that must be struck. Everything from making coffee to deciding which car to purchase has a sense of balance or efficiency that must be considered to avoid wastefulness. No matter what career path students choose, this lesson and its themes should serve them well.

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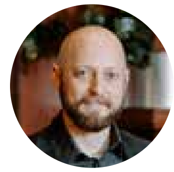

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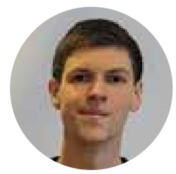

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