WISELearn Resources

Career
Academy
Teacher
Externship
Program

Title: Reverse Engineering a Manufacturing Component

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Externship Business: Walker Forge

Overview / Description:

The scenario is that the student is working in the engineering department of a manufacturing plant. The plant has access to a wide variety of machining tools, so it is customary for them to make or repair their own parts as things wear out. Many of the parts are unique to the equipment at the facility, so it is impossible to simply order one from some outside supplier. Even if a part was available, it is cost prohibitive to buy new.

Students will be provided with a small piece of machinery that they must reverse engineer the dimensions. For middle school level students, the geometry will be kept rather simple and the measurements straightforward. For high school students, the geometry can become more complex, requiring some drafting skill, caliper use, and higher level CAD design.

Once the students take all the necessary measurements, then using CAD (Tinkercad for the lower grades), they will build up a virtual mock-up of the part. From there, the option would be to teach additive or reductive design. The part could be recreated using either a CNC or 3D printer.

Subject(s):

Math, Science, Technology

Grade Level(s):

Grades 6-12, depending on difficulty. This plan is written for middle school, but can be scaled up.

Learning goals/objectives:

After completing this activity, students should be able to:

- Measure correctly using a tape measure and/or caliper
- Convert measurement units correctly from standard to metric and vice versa
- Draw the part on paper to scale (high school drafting experience recommended)
- Draw the part on a 3D CAD design program to scale
- Recreate the part using a 3D printer or CNC

Type of Activity:

- ✓ Individual
- ✓ Small Group
- ■ Whole Class

Teaching Strategies:

- ✓ Discussion
- ✓ Partner work
- ✓ Use of Technology
- ■ Role Playing
- ■ Simulation
- ✓ Performance Assessment

Content Standards

Wisconsin Standards for Science

Crosscutting Concept 3: Scale, Proportion and Quantity

> **SCI.CC3.m** - Students observe time, space, and energy phenomena at various scales using models to study systems that are too large or too small. They understand phenomena observed at one scale may not be observable at another scale, and the function of natural and designed systems may change with scale. They use proportional relationships (e.g., speed as the ratio of distance traveled to time taken) to gather information about the magnitude of properties and processes. They represent scientific relationships through the use of algebraic expressions and equations.

Crosscutting Concept 4: Systems and Models

> **SCI.CC4.m** - Students understand systems may interact with other systems: they may have sub-systems and be a part of larger complex systems. They use models to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems. They also learn that models are limited in that they only represent certain aspects of the system under study.

Science and Engineering Practices 1: Ask Questions and Define Problems

> **Sci SEP1.A.m:** Ask questions to clarify or refine a model, an explanation, or an engineering problem.
>
> **SCI.SEP1.B.m** Students define a design problem that can be solved through the development of an object, tool, process, or system, and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.
>
> **SCI.SEP2.A.m** Students develop, use, and revise models to describe, test, and predict more abstract phenomena and design systems. This includes the following: Evaluate limitations of a model for a proposed object or tool. Develop or modify a model—based on evidence – to match what happens if a variable or component of a system is changed.

SCI.SEP4.A.m Students extend quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. Analyze data to define an optimal operational range for a proposed object, tool, process, or system that best meets criteria for success.

SCI.SEP5.A.m Students identify patterns in large data sets and use mathematical concepts to support explanations and arguments. This includes the following: Decide when to use qualitative vs. quantitative data. Use digital tools (e.g., computers) to analyze very large data sets for patterns and trends. Use digital tools and mathematical concepts and arguments to test and compare proposed solutions to an engineering design problem.

Engineering, Technology, and the Application of Science 1:

SCI.ETS1.A.m The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.

SCI.ETS3.B.m Science asks questions to understand the natural world and assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation. Science carefully considers and evaluates anomalies in data and evidence. Engineers develop solutions using multiple approaches and evaluate their solutions against criteria such as cost, safety, time and performance. This evaluation often involves trade-offs between constraints to find the optimal solution.

Wisconsin Standards for Mathematics:

Measurement and Data

CCSS.MATH.CONTENT.5.MD.A.1 - Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.

CCSS.MATH.CONTENT.5.MD.B.2 - Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8). Use operations on fractions for this grade to solve problems involving information presented in line plots. For example, given different measurements of liquid in identical beakers, find the amount of liquid each beaker would contain if the total amount in all the beakers were redistributed equally

CCSS.MATH.CONTENT.5.MD.C3 - Recognize volume as an attribute of solid figures and understand concepts of volume measurement.

CCSS.MATH.CONTENT.5.MD.C.4 - Measure volumes by counting unit cubes, using cubic cm, cubic in, cubic ft, and improvised units.

CCSS.MATH.CONTENT.5.MD.C.5 - Relate volume to the operations of multiplication and addition and solve real world and mathematical problems involving volume.

Geometry

CCSS.MATH.CONTENT.7.G.A.1 -Solve problems involving scale drawings of geometric figures, including computing actual lengths and areas from a scale drawing and reproducing a scale drawing at a different scale.

CCSS.MATH.CONTENT.7.G.A.2 - Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions. Focus on constructing triangles from three measures of angles or sides, noticing when the conditions determine a unique triangle, more than one triangle, or no triangle.

WI Information Technology Standards:

Empowered Learner

EL2.a.3.m: Navigate a variety of digital tools to choose, use and troubleshoot technologies to create new knowledge.

EL3.a.3.m: Transfer and apply skills to begin troubleshooting and exploring emerging technologies.

Innovative Designer

ID1.b.3.m: Demonstrate an ability to persevere through authentic, open-ended problems by applying abstract concepts with greater ambiguity.

ID2.a.3.m: Use a deliberate design process to generate ideas, create innovative products, and test theories as possible solutions.

ID2.c.3.m: Engage in an iterative process to develop and test prototypes; understand and appreciate that failures or setbacks are opportunities for growth and improvement.

Length of Time and length of class periods:

3-5 45-minute class periods, depending on prior knowledge for the low and high end of time.

Materials List:

- Ideally, get some simple geometric-shaped objects that are cast-offs from a local manufacturer. Items must be small if you intend to 3D print them. Otherwise, get various hardware parts from a hardware store that are small in size and have simple geometry for measurement purposes.
- Rulers, tape measure, calipers
- 3D printer, filament
- Computer
- Reverse Engineering Rubric

Directions (Step-by-Step):

Day 1: Introduce the situation of the part needing replacement. Discuss and problem solve how the students are going to engineer a solution. After some discussion, introduce the concept of reverse engineering (perhaps students came up with this idea on their own).

Teach students how to measure using each measuring tool if not taught prior, otherwise review. Ensure students know how to read the instrument correctly using fractions and the correct units of measure. Teach students how to convert units of measure, if not taught prior.

Students practice taking measurements and converting units the remainder of the time, leaving 5-10 minutes for wrap up for the day. Wrap up by regrouping the class and seeing if groups or individuals that are measuring the same item measured it in the same locations and have similar answers.

Day 2: Prior to lesson, determine if this is going to be done individually or in small groups. This depends on your preferences as well as the number of items available. There are advantages and disadvantages to singular and groups.

Students will now for the first time see the actual part they will need to recreate. Hand out the parts to each individual or group and let them study it. Ask them if they know what the part is used for in real life. Discuss with the class issues that may come up with certain measurements and solutions for finding answers. (Good geometry review). Distribute measurement tools and paper and allow for enough time to draw/draft a sketch of the item. Discuss 3D and the XYZ planes so that students consider drawing multiple sketches to see the item from various sides. As they take measurements, students can add the numbers in around their sketch. Allow time for group discussion and comparison of measurements.

Day 3: Students who have completed their measurements and sketches are now ready to create a 3D image in CAD. For middle school, Tinkercad is a good online program to use for this. We will assume students have already created accounts on Tinkercad and are familiar with the program. (If not, add at least a week to get that all set.)

In Tinkercad students will drag out various shapes onto the workplane. Here they can resize, group, ungroup, make holes and join shapes to finish the design. The rate at which a student competes this portion of the project depends on their skill with the program and the complexity of their part.

Day 4: Students who have completed their CAD design will share it with their peers while holding up the original part. Peers provide feedback to the accuracy of the design. When completed and approved by the teacher, the student downloads the .STL file and turns the file in to the teacher. The teacher will then 3D print the object when the printer is available.

Wrap-Up:

Day 5: Students hold their printed item next to the original. If the original item isn't plastic, make believe it is. Have students compare the two by measuring again with their tools. Discuss the project in small groups and later share out to the entire class. Reflect on what is learned. Remind students that this process is one undertaken by engineers on a daily basis in their work.

Formative/Summative Assessment:

- Formative assessments can be done through observation in reviewing the measurements taken during practice, later during the measurement of the real item, and in the process of getting the CAD design cleared to print.

- Summative assessment is the completion of the print and comparing the two items, using the Reverse Engineering Rubric.

Extension Activity for differentiation:

- This activity could be extended to more difficult parts that are more complex in their geometry.
- Students could also research further additive vs. subtractive means of reproduction.
- Finally, if a materials engineer is available, have them come in as a guest speaker to share the reality of this project.

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Reverse Engineering Rubric

Criteria	Proficient (85-100)	Average (70-85)	Poor (<70)	Student's score
Student's use of Tinkercad	Student is able to use the program efficiently and correctly. They have the technological skill to create the 3D image without issue.	Student can use Tinkercad, but still needs some assistance in creating the correct images. Makes some scaling or measurement mistakes.	Student's use of Tinkercad is not fully understood. The shapes selected are not ideal to the re-creation of the item. The student's use of geometry, scale, measurement are incorrect.	
Student's 3D printed design	Student's print contains the correct geometry to match the original item. Measurements are within <3% error on any side.	Student's print is close to the original geometry to match the original item. Measurements are in the range of 3-10% error	Student's print is not accurate enough to print, incomplete, or has measurement errors in excess of 10%.	

Comments: