MANUFACTURE
YOUR PATH

DESIGN FOR MANUFACTURING

Topic(s): Engineering design, measurement and fit, g-code

Grade level(s): 9th – 12th grades

Time: 45-60 minutes

TEKS Alignment: HS.M.PM.2.C, HS.M.PM.3.E, HS.M.DMI.4.C, HS.M.DMII.4.A, HS.M.ME.2.C

ACTIVITY OVERVIEW

In this activity, students are introduced to the work of engineers in the manufacturing field. Students will be challenged with designing a custom part for a new product. Students will need to choose the correct tools to gather precise measurements as well as draw the needed part with labels for part lengths and angle connections. Once students have completed their design, they will be challenged to rapid prototype with the use of a 3D pen. To model prototyping with a 3D printer, students will develop the g-code for the pen handler to interpret and follow to create the design. Once created students can test to see if their part fit well and redesign to get tighter tolerances.

TABLE OF CONTENTS

ALIGNMENT TO STANDARDS

Texas Essential Knowledge and Skills (TEKS):

Principles of Manufacturing

HS.M.PM.2.C Use a variety of measuring instruments
HS.M.PM.3.E Use appropriate units of measure

Diversified Manufacturing I

HS.M.DMI.4.C Experiment with different manufacturing materials such as plastic, composites, fiberglass, stone, and wood.

Diversified Manufacturing II

HS.M.DMII.4.A Develop a CNC program using a computer-aided manufacturing program.

Manufacturing Engineering Technology I

HS.M.ME.2.C Fabricate a prototype design of a mechanical part.

LEARNING OBJECTIVES

Students will know:

- How to measure with rulers and protractors.
- What 3D printers are and the types of software used to communicate with the device.
- What rapid prototyping is.

Students will understand:

- When to use different measurement tools.
- The computing side of 3D printing and uses for CAM software with other equipment.

Students will be able to:

- Measure a provided part for lengths and angle dimensions.
- Select a schematic of the part needed with accompanying measurements and tolerances.
- Use a 3D pen to rapid prototype and edit designs for fit and function.

CAREER CONNECTIONS

Metrologist

By evaluating and calibrating the technology in our everyday lives, metrologists keep our world running smoothly.

Work Environment: Workers in scientific and legal metrology are usually employed by government agencies. But most metrology workers have jobs in industrial metrology, where they test new products for private companies as well as for government.

Duties: Professionals in these jobs have the following duties and more: supervise the manufacture of products, test manufactured components, check assembly process to ensure that machinery is functioning correctly, develop tests to evaluate a structure's resistance to stress.

Source: https://www.bls.gov/careeroutlook/2009/fall/art02.pdf

Industrial Engineers

Industrial engineers design, develop, and test integrated systems for managing industrial production processes.

Work Environment: Industrial engineers work in a variety of settings, such as offices and manufacturing plants. Industrial engineers work in a variety of settings. For example, they may observe workers assembling parts in a factory or spend time in an office analyzing data.

Duties: Professionals in these jobs have the following duties and more: evaluate manufacturing, delivery, customer experience, or other systems and identify ways to improve productivity and quality, design processes, systems, or enhancements to maximize productivity, efficiency, or space, and analyze data to identify trends and areas for improvement.

Median US Salary: $99,380 (US Bureau of Labor, 2023)

Source: https://www.bls.gov/ooh/architecture-and-engineering/industrial-engineers.htm#tab-1

Mechanical Engineers

Mechanical engineers design, develop, build, and test mechanical and thermal sensors and devices.

Work Environment: Mechanical engineers generally work in offices. They may occasionally visit worksites where a problem or piece of equipment needs their personal attention. In most settings, they work with other engineers, engineering technicians, and other professionals as part of a team.

Duties: Professionals in these jobs have the following duties and more: design or redesign mechanical and thermal devices or subsystems, using analysis and computer-aided design, develop and test prototypes of devices they design, and oversee the manufacturing process for the device.

Median US Salary: $99,510 (US Bureau of Labor, 2023)

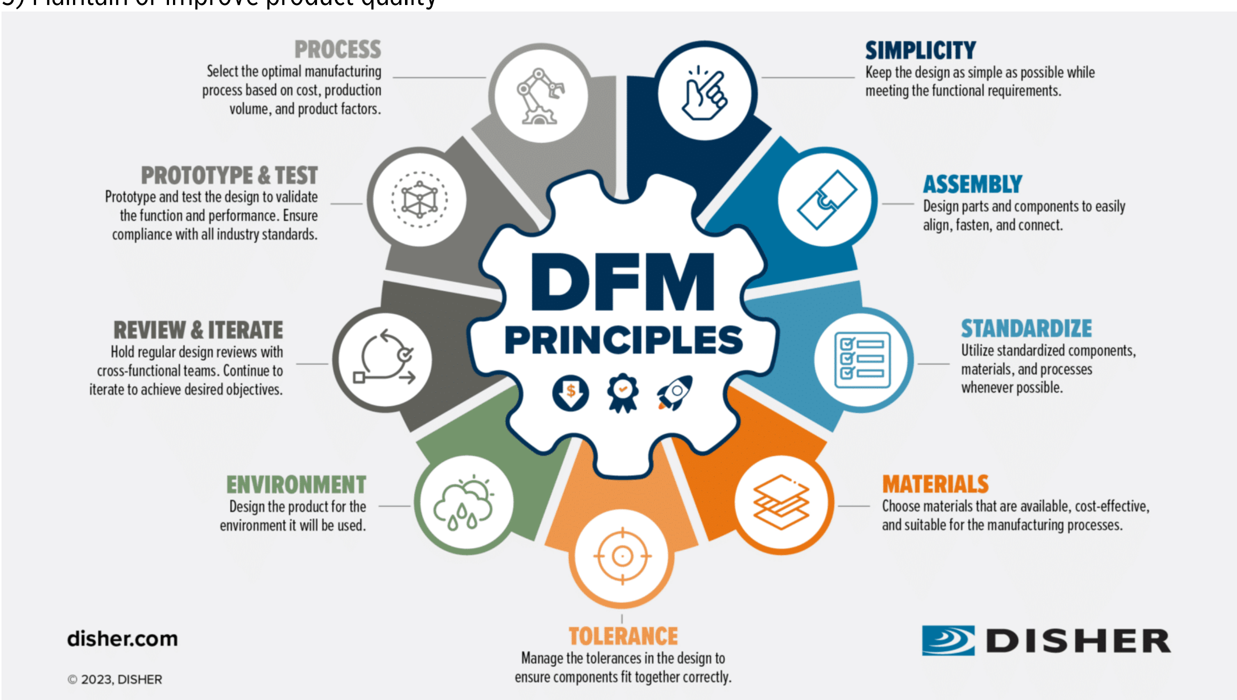
Source: https://www.bls.gov/ooh/architecture-and-engineering/mechanical-engineers.htm#tab-1

BACKGROUND INFORMATION

In this activity, students will have the opportunity to see rapid prototyping within one class period. They will do this using a 3D pen. With this activity, conversations about engineering careers and design for manufacturing can be discussed.

Design for Manufacturing (DFM) makes you sustainable as a manufacturer. It strengthens your ability to save money, improve quality, and increase speed. DFM is a valuable approach to product development. DFM optimizes the design of a product to make it easier and more cost-effective to manufacture. It should begin during the early conceptual design stage of product development. And it should continue through detailed engineering. By implementing DFM, manufacturers can save significant costs.

The 3 Goals of DFM
1) Streamline and simplify the manufacturing process
2) Reduce manufacturing and assembly costs
3) Maintain or improve product quality



https://www.disher.com/blog/design-for-manufacturing/

Additional Resources

Your Ultimate Guide to Design for Manufacturing
- https://www.studiored.com/blog/design/design-for-manufacturing/

3D Printing G-Code Tutorial
- https://www.simplify3d.com/resources/articles/3d-printing-gcode-tutorial/

PRE-ACTIVITY RECOMMENDATIONS

Students should be familiar with measuring acute angles with a protractor. The link below has multiple levels of difficulty and allows for practice if physical protractors aren't available.

Measuring Angles
(https://www.transum.org/software/SW/Starter_of_the_day/Students/Measuring_Angles.asp?Level=4)

POST-ACTIVITY RECOMMENDATIONS

Students can explore 3D modeling with Tinkercad and if a 3D printer is available, print their own designs!

3D Design & Print with TinkerCad (https://uviclibraries.github.io/3d-design-print/)

TinkerCad Sketch Tool (https://www.tinkercad.com/blog/sketch-tool)

ACTIVITY FILES

The Manufacture Your Path classroom activity set includes all of the materials needed for 15 student stations. In the case that you would like to create more of the custom items, the files described below can be downloaded from our website.

1. Irregular Polygon (Irregular Polygon.svg)
    a. This SVG file can be cut and engraved with a laser cutter/engraver.
    b. This design is made of two 1/8" layers. The first layer should be the square cut and the second layer should have the square cut as well as the interior cut. The two pieces are then glued together.
    c. We recommend using 1/8" plywood or acrylic for these. Make sure that the color contrast allows for the rulers to still be used.

STUDENT STATION SET-UP

Students will work in pairs at an individual station. Each station is comprised of one pencil case of materials.

1. One pencil case including:
    a. 3D pen
    b. USB power pack and USB cord
    c. 2 Lasercut 3D part shapes (irregular polygon)
    d. Ruler
    e. Protractor
    f. Silicone mat
    g. Heat protectant gloves
    h. Refill filament
2. Designs on graph paper

LESSON PLAN

Introduction (5-10 min)

- Welcome students to the classroom and direct them to take a seat.
- Explain to students that they will be acting as design engineers at a manufacturing company.
- Ask students if they have heard of engineering before? If so, what do engineers do in the manufacturing industry do?
    - While many students may think of engineers who design a specific product (civil- bridges and buildings, mechanical- mechanical systems, engines, chemical- foods, makeup), manufacturing engineers are more focused on the process to make a product.
    - Some things that a manufacturing engineer may have to consider are:
        - How do we manufacture this design?
        - How can we make it faster/cheaper?
        - What machine do we need to make this part?
        - Where should that machine go in the plant?
        - How can we get more consistent results from our process?
- Explain to students that engineers in the manufacturing industry create designs that will work for the intended plans by implementing design for manufacturing (DFM) principles.
- Ask students what considerations an engineer might think of when planning a process to manufacture a product?
    - What tools/equipment/materials are available? What will work best for the function needed?
    - Are there premade components that can be used?
    - Is the design as simple as it can be?
- Describe to students that one of the principles of DFM is to prototype and test a design before deciding on the final process.
- Explain that in this activity, students will be focused on creating a design and rapid prototyping with a 3D model.

Part 1: Measurement and Schematic (15 min)

- Have students turn to page 2 and direct them to find the following items at their station: ruler, protractor, and acrylic design (2).
- Explain that the students will need to design a custom piece to fit into this new part with a unique hole design. Explain that in order to decide on the design needs, we need to start with an assessment of the hole itself.
- Explain that students will need to record the length of each side and each angle with notes about how those measurements should change to ensure the unique part fits snug within the hole.
    - Students can do this free form or can be provided more structure. One student can be assigned to collect the side measurements and one student can be assigned to measure the angles.
    - If needed, review how to use both tools.
        - If students have done the metrology activity, ask them if we should take measurements in inches or centimeters? You can let them know that the rulers and protractors have all been calibrated and are measuring accurately.

            - Measurements should be taken in centimeters to get the most precise values.
        - Make sure to review how to use a protractor to measure angles. Remind students that our protractors can only measure between 0 to 180 degrees. This means that for some angles we will take an internal measurement (for example, the angle at the top of the "ear") and for others we will need to take an external measurement (for example, the angle between the "head" and "neck").
            - To take a measurement with the protractor, align its center point with the vertex of the angle, then align one side of the angle with the protractor's zero line, and finally, read the degree measure where the other side of the angle intersects the protractor's scale. Keep in mind that if aligning the zero line on the left, the angle measurement will be on the exterior of the protractor. If aligning the zero line on the right, the angle measurement will be the interior scale.
- Discuss with students as they finish, how much wiggle room they think they will need to 3D print the part to fit inside the hole.
    - Help students to understand that the measurements they took are just beyond the max size that will fit within the hole.
    - You can discuss how the adjustments to the design are heavily influenced by the type of equipment being used. Have students think of 3D printers as fancy hot glue guns. Ask them if they used those exact measurements and traced it with a hot glue gun if they think the design would fit inside the hole. You can also discuss how if we had a laser cutter or CNC our design adjustments would be different.
    - Explain that deciding how much smaller the design needs to be is not clear cut which is why engineers rely on rapid prototyping to test a design before committing to it.
- Once measurements are taken, distribute the design options to student groups. Direct students to compare the design options to their measurements and to select the design they'd like to move forward with at this time.
    - For students that get stuck trying to get the perfect solution or take long to commit to a decision, let them know that there will be opportunities to test multiple designs as we rapid prototype.

Part 2: G-Code and Rapid Prototyping (20-30 minutes)

- Explain that 3D designs are often created in a platform that has software to "slice" the design into layers to provide instructions to the 3D printer. These instructions are g-code.
- Ask students what types of information are provided in g-code?
    - What temperature to heat to, how fast to move, where to move, how much filament to extrude, what to set the bed temperature to, whether or not to have a fan on.
    - G-code is also used for CNC machines and would have other codes specific to selecting an appropriate tool or other specific functions.
- Explain that because we'll be using 3D pens, we'll have one person acting as the 3D printer and we will need to write the code for the 3D printer to follow.
- Direct students to look to the last page of their packet for examples of codes they will need in their 3D printing instructions.

- Overall students should have the following steps written (heating and homing can be reversed):
  - Home the nozzle- direct it to go to a set location (0,0,0)
  - Begin heating- turn the 3d pen on
  - Determine if they'll use absolute or relative positioning
  - Commands for where to move around the coordinate grid.
- Explain that they should include details for the feed rate (speed that the nozzle moves) and extrusion amounts (how much filament to feed through the device at that step), even though we will not be able to truly control those in our test.
  - For advanced students, you can have them use the provided formula to determine the extrusion rate. This accounts for the cross section of a 1.75mm filament to determine the total volume of filament needed for the desired line width and layer height.
- A full example of the g-code can be found in the activity key.

- Once students have finalized their g-code their partner, the 3D printer, can use the 3D pen to create the prototype. Review safety notes about the 3D pen as well as how to operate.
  - All students using the 3D pens should wear heat resistant gloves. The tip of the pen heats to temperatures above 190 degrees Celsius in order to melt the filament. Students should not touch this area of the pen with or without gloves on.
  - All 3D prints must be done on the provided silicone mat. This heat safe mat ensures that their design cools quickly and that the school materials are undamaged. This clear mat should be placed over their design option for easier tracing.
  - The 3D pen needs to be connected to the power bank to function. Once plugged in, a red light will turn on. To start heating the nozzle, press the feed button (arrow pointing to the nozzle). The green light will flash and will hold steady when holding at the set temperature.
  - To load filament, straighten the end of the filament if necessary and insert it into the filament loading hole until it stops. Press and hold, or double click the feed button to load filament into the pen. Sliding the speed control all the way up will make this process faster.
  - Once loaded, you can print away! Set the speed control (start slow and go faster after practice), then press and hold the feed button to start printing. You can also turn on continuous feed by pressing the feed button twice (turn it off by pressing the feed or withdraw buttons (arrow pointing away from the nozzle) once.
- As students get the border of their designed traced, remind students to also add connections across the design to hold the structure together without bending/warping. The design does not need to be completely filled in, but a zig zagging pattern within the design will allow for the exterior shape to be maintained.
- Once students have finished their prototype, they can test their design in the acrylic hole. If the first design didn't fit, students should make observations about what didn't work and (1) pick a new provided design to trace or (2) draw their own design to trace. It is also recommended that students switch roles so another person can try the 3D pen.

    - Explain that rapid prototyping is essential to quickly try designs and make improvements. A failed prototype doesn't mean failure but ideas for what to change.
- If there is time available, students can be challenged to create a new g-code for a takeaway (their name/initials, or a school appropriate drawing).
- Explain that the skills they used in this activity and the knowledge they acquired/honed are essential to a career in engineering. Explain that the manufacturing industry needs manufacturing engineers to design the best processes to develop products.

3D pen filament can remain in the 3D pen if they will be used again that day. If not, it is recommended to remove the filament before turning the devices off. To remove the filament, press the withdraw button (arrow pointing away from nozzle) until the filament is free (you may need to lightly pull on the filament while holding the button).