3-D Spatial Visualization Skill Building for Additive Manufacturing

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Abstract:
Additive Manufacturing, or 3-D printing, is the process of making a three-dimensional object using an additive process where the object is built by laying successive layers of material to shape the object. This distinguishes AM from traditional manufacturing where machining techniques that rely on removal of material by cutting, milling or drilling (subtractive process) are used.

Spatial Visualization has become a required skill set in this growing field and there is a revitalized educators' interest in SV because historically SV skills were believed to be learned as a "by-product" of graphics (CAD) education. However, research shows that work with solid models versus a computer screen is necessary. This module builds 3-D visualization skills using a manual technique (manipulation of a solid object on a virtual build platform). Students are introduced to the Orthogonal Cartesian Coordinate System, types of positive rotations possible, and orienting an object on the build platform with relation to the operator and with relation to the machine.

Module Objective
Develop background knowledge and practice in using 3-D spatial visualization skills as applied to additive manufacturing tasks.

Student Learning Objectives
Students will be able to:

- Use the Right-Hand-Rule to rotate a cube about its X, Y and Z coordinate positions at 0- or 90-degree or 180-degree, or 270-degree increments.
- Given a position on the build platform, orient a cube correctly 100% of the time (e.g.: 0-degrees on the X-axis, 90-degrees on the Y-axis, etc.).
- Label a cube's orientation based on its position on the build platform (0 or 90-degree, 180-degree, or 270-degree).
- Describe the following terms: Orthogonal Coordinate System, Build Platform, Orientation, Additive manufacturing, Spatial Visualization, Mental Rotation.

MatEdU Core Competencies Covered

10A, a1 – Define the terms used in the Coordinate Systems in Additive Manufacturing
10A, a2 – Differentiate part orientation using X, Y, Z coordinates in the build platform
10A, a3 – Define and illustrate orthogonal orientation notation of a part
10A, a4 – Demonstrate the right-hand-rule for positive rotations with reference to the build volume origin

Key Words

3-D spatial visualization, orthographic projection, orthogonal coordinates, mental rotation, right-hand-rule, Cartesian coordinate systems, additive manufacturing, build platform, part orientation

Type of Module/Mode of Presentation

PART 1 – Interactive presentation (using slides and resources) to introduce concepts to be learned.
PART 2 – Hands-on activity that gives students practice in manually orienting a 3-D solid object.
PART 3 – Motivational presentation to assess knowledge gained and encourage further learning.

Time Required

60 minutes, add additional 45 minutes if optional exercise is included.

Pre-requisites

Basic understanding of linear Coordinate Systems and the coordinate plane.

Target Grade Levels

High school, upper grades, to entry technician level

Table of Contents

Equipment and Supplies Needed

- ☐ Resources (see list provided with each activity)
- ☐ Examples of 3-D manufactured parts

Per person/team:

- ☐ Small (2”x2”) paper cubes (boxes) available from hobby/gift stores
- ☐ Large (12”x12”) piece of cardboard or stock paper (build platform) available from hobby/gift stores
- ☐ Sharpies/pens

FIG 1: Cube (to be assembled as 3-D object) and build platform

Curriculum Overview and Instructor Notes

There are three parts to this module:

PART 1 – An interactive presentation

…introduces key concepts and terms such as coordinate system used in AM, right-hand-rule, and the build platform. Included in the presentation is a verbal pre-evaluation to assess how much students know about 3-D Spatial Visualization.

PART 2 – The hands-on activity

…gives students practice in manually orienting a 3-D solid object, rotating it, and correcting orientations. An optional exercise gives students practice in figuring out/troubleshooting an orientation sequence that lands the object in a pre-determined orientation on the build platform (i.e. upside down).

PART 3 – A motivational activity

…shows students what they can do with what they learned about 3-D Spatial Visualization. Examples of 3-D objects created through AM process are used to generate interest and conversation. This activity can be used to assess how much students learned about 3-D Spatial Visualization. Independent practice is assigned for students to take the mental rotation test (MRT) online and do research about spatial visualization.

Safety

Take any necessary precautions before you start.

Terms to know (and use)

3-D spatial skills have 2 components: spatial visualization and spatial orientation.
Spatial visualization is the manipulation of an object configuration, whether it be rotated, folded, repositioned, or otherwise transformed. There are two kinds:

- Mental rotation (the main focus in this module) is the ability to mentally rotate an object about the axis of a Cartesian coordinate system
- Mental transformation ability to mentally manipulate an image into variety of arrangements. Paper folding and the ancient art of origami are two good examples.

Spatial orientation involves being able to mentally move your viewpoint while the object remains fixed in space.
Rotating Objects is one of the fundamental tasks in 3-D modeling.
Object Rotations are either:

- Positive (clockwise), depending on viewpoint used (operator/machine); or
- Negative (counter clockwise), depending on viewpoint used (operator/machine).

Types of rotations are by degrees, e.g.: 90,180, 270, and 0.
3-D Cartesian coordinate system, **right-handed,** is a tool used to orient objects correctly about the X-, Y-, and Z-axis in the machine. The axis: X, Y, and Z meet at right angles to one another, i.e.: are perpendicular, making them Orthogonal coordinates. In 3-D printing, the print head moves to the correct

X/Y/Z position to place material in the layers from the bottom up. (Y-axis represents length, X width, and Z height/depth)

Build platform (of the machine): any base which provides a surface upon which the build is started and supported throughout the build process.

Object orientation: refers to how the object is facing toward the planes formed by the X-, Y-, and Z-axis. The object face is identified by degrees: 0-degrees, 90-degrees, 180, and 270. NOTE: there are far more degrees on which to orient an object, these 4 are used in this module. Also referred to as object placement.

Other related terms:
Print head and Print bed: Print bed (also known as the build platform) is the surface where the part sits on. As the print head moves to the XYZ coordinate position, the material is squeezed out of the nozzle and deposited on the print bed in successive layers.

Visual penetrative ability is building a mental picture of what's inside of an object.

Also related:
- Orthographic projection
- Orthogonal coordinates
- Object transformations
- Object reflections

Module Procedures

PART 1 – Interactive Presentation

Resources (slides) have been provided to introduce key concepts and terms used in the module. Included in the presentation is a verbal pre-evaluation to assess how much students know about 3-D Spatial Visualization, this is known as the KWLD Chart (what you KNOW, WANT to know, want to LEARN, and what you can DO with what you learned). The first half of the KWLD chart is done to assess readiness, the second half is done later to assess learning and motivation.

Directions	**Resource**
Tell: Spatial visualization is the manipulation of an object configuration, whether it be rotated, folded, repositioned, or otherwise transformed.	
Write on a chalk board/poster paper: "KWLD" Ask:	Slide KWLD chart

“What do you know about Spatial Visualization?” Write answers next to the letter “K” “What do you want to know?” Write answers next to the letter “W”	
Tell: If you recall, in the 2-D world there are the X- and the Y-axis, and along each axis is a numerical point, the coordinate for that exact point on that plane. And we plot those points. Point out negative directions as well. 2-D Cartesian coordinate systems are linear.	Slide 2-D Cartesian Coordinate System (X- and Y-access, positive and negative)
Tell: In order to be able to print a physical object, a 3-D printer needs to be able to move on 3 Coordinate Axes (length, width, height/depth); this is referred to as an Orthogonal Cartesian coordinate system. The three axis are perpendicular/right angle to each other, making them Orthogonal Cartesian coordinates. Orthogonal literally means at right angles. In 3-D printing, the print head moves to the correct X/Y/Z position to place materials in the layers from the bottom up. The coordinates help us know where to tell the print head to start and move to. The coordinates are also helpful in orienting the object correctly in the machine AND, in troubleshooting should the print have issues.	Slide 3-D Axis
Explain the **Right-hand Rule:** To help us correctly orient a 3-D object and set up the print program, we have this tool called a right-hand-rule.	Slide Right-Hand-Rule

Index finger represents the Y-axis Thumb represents the X-axis Middle finger represents the Z-axis Repeat: X = width Y = length Z = height/depth of a 3-D object	
Discuss orientation and point-of-view/perspective: The XY-plane is horizontal and the Z-axis points up. When placed on the build platform: The X axis (your thumb) runs across your chest, and for most machines, this also indicates the front of the machine. Rotation about each axis is clockwise. To establish this (the machine's) point of view/perspective, you must imagine looking down your finger/thumb from the tip, like looking down a tube. Point out the green arrows. We use a cube because it is the simplest 3-D object to rotate about the 90, 180, and 270-degree positions for illustration of this concept. Also, note that the X- and the Y-axis form a positively oriented two-dimensional coordinate system in the XY-plane if observed from above the XY-plane. Most but not all machines print only on the positive planes.	Slide Bird's-eye-View
Walk through examples of positive rotations about each axis with the cube. Start and end with 0-degree orientation on the X-axis (marked with a green dot	Slide Example Positive Rotation Sequences (About X, Y, and Z-axis) NOTE: these slides are hidden, and are to be used as reference for

on the cube). Follow the dot about the axis (ball arrow on the slide), pointing out the objects orientation and position. Things to note at rotation about the X-axis: at 180-degree rotation, the bottom is the top and at 270-degree rotation the dot is positioned on the bottom of the build. Discuss importance of the top and bottom of the build. Suggest having an example object e.g. a plastic car and discuss issues with positioning the object upside down. Things to note at rotation about the Y-axis: The 0-degree orientation on the X-axis never changes. Things to note at rotation about the Z-axis: The bottom is always positioned down on the build.	instructor, however, if chosen, can be displayed to student.

PART 2 - Hands-on Activity

The hands-on activity gives students practice in manually orienting a 3-D solid object, rotating it, and correcting orientations. An optional exercise gives students practice in figuring out/trouble shooting an orientation sequence that lands the object in a pre-determined orientation on the build platform (i.e. upside down).

Directions (can be done individually or in pairs):

1) Hand out cubes and the build platform (12 x 12” square of paper/cardboard).
2) If the box is in collapsed form, instruct to assemble the 3-D object (cube).
3) Get hand in Right-hand-rule position on the build platform with thumb (X coordinate) running across your chest.
4) Place cube on the platform starting with object’s 0-degree side facing the front of the build platform (this is its orientation), instruct to place a mark on the 0-degree side.
5) Complete a full rotation sequence around one axis while explaining **positive rotation** (for 3-D objects) can be from the machine’s perspective or from the operator’s within that plane, you must establish your orientation, we are rotating from the machine’s perspective.

6) Instruct students to follow along doing a positive rotation of the object at 90-degrees on its X-axis, 180-degrees on its X-axis, and 270 on its X-axis. Finish by bringing it back to 0-degrees rotation (where you started).
7) Repeat for Y and Z. See slides for examples.
8) Observe performances, correct as needed.
9) Mix it up. Establish a machine's perspective and devise several rotation sequences for students to follow along with, mixing up rotations about each axis. TIP: It's good to have an end orientation in mind for the sequence. For example, in the Example Positive Rotation Sequence provided, an orientation of 0-degree object orientation facing front of the machine was the start and end goal so the object is moved through a sequence so that it ends with its 0-degree orientation facing the front of the machine. Be sure to write down your sequences as illustrated on the slide and be sure to discuss observations as you move through the sequence.

   Example of a simple sequence using all of the axis rotations, 90-degrees at a time:

   a. Rotate the object about the X-axis 90-degrees
   b. Rotate the object about the Y-axis 90-degrees
   c. Rotate the object about the Z-axis 90-degrees
   d. Rotate the object about the X-axis 90-degrees again
   e. Rotate the object about the Y-axis 90-degrees again
   f. Rotate the object about the Z-axis 90-degrees again
   g. Point out that the object is returned to its starting position. Discuss when this would be useful, i.e.: establishing best orientation to begin a build, etc.

OPTIONAL

10) Give an object orientation and have students correct it with a positive rotation sequence in as few rotations as possible. A fun one and the most critical one is to orient the object upside down. Discuss what is wrong with that orientation and have them correct it using as few positive rotations as possible. In real-life this exercise demonstrates how to input rotations on axis to achieve a position/orientation for the build. When you load the STL file, you must identify the object's face that you want to be the base, you can orient and re-orient the object by entering values in degrees rotation/position. This is helpful to know and be able to do if for example your object happens to load upside down, you can put in a value: 180 on the X- or Y-axis to right the object.

PART 3 – Motivational Activity

This motivational activity shows students what they can do with what they learned about 3-D Spatial Visualization. Suggest bringing in some examples of 3-D objects created through AM process to get the conversation going. Using the KWLD chart to complete the last two items, "L" and "D", will give insight into gaps or needs for further instruction. Independent exercise is assigned to take a mental rotation test and research the future and application of additive manufacturing.

Directions	Resource
Return to the chalk board/poster paper with the KWLD chart: Ask: "What did you learn about Spatial Visualization?" Write answers next to the letter "L" "What can you do with what you learned?" Write answers next to the letter "D" Use examples of 3-D objects to start them talking, be ready to provide a periodical or news article about AM innovations and application.	Examples of 3-D objects created through AM Articles (see Resources section in this module)

Directions for extended (optional) activity:

1) Provide URLs for students to research spatial visualization. A resource for the Mental Rotation Test (MRT) has been provided (see References).
2) Provide other URLs/resources to assist with research.
3) Allow time for research (suggest at least one class period).
4) Instruct students to report observations (NOTE: the MRT resource provides a score).

References

A Mental Rotation Test (MRT)
http://www.iq-test.com/spatial-ability-test.php

3-D Printing for Beginners
http://3-Dprintingforbeginners.com/3-D-printing-technology/

Spatial Visualization – Cognition
https://en.wikipedia.org/wiki/Spatial_visualization_ability

Terms Used in Additive Manufacturing
http://materialseducation.org/modules

Evaluation Packet

Student evaluation questions (discussion/quiz)

1) Provide students with several tasks (sequences of positive rotations) that demonstrate the following (observe for correctness):

- Use the Right-hand-Rule to rotate a cube about its X, Y and Z coordinate positions at 0 or 90-degree, 180-degree, or 270-degree increments.
- Answers: Performance will vary depending on sequence task provided.

2) Provide students with a position on the build platform, instruct to orient a cube correctly to demonstrate the following positions (observe for correctness):
   - Starting with 0-degree side facing the X-axis, orient the object's 0-degree side facing the back of the machine.
   - Starting with 0-degree side facing the Y-axis, orient the object's 0-degree side facing you.
   - Answer: Performance will vary depending on position provided. The two main positions to know are the front and back of the machine. Also, important to recognize that you, the operator's position, can change, but in most cases, at the front of the machine.
3) Label a cube's orientation based on its position on the build platform (0 or 90-degree, 180-degree, or 270-degree about the X-, Y-, and Z-axis)
   - Answer: Always start with 0-degree side facing the axis to be rotated about; each side will be labeled accordingly for each axis, an example for X-axis is in the slide show.
4) Describe the following terms: Orthogonal Coordinate System, Build Platform, Orientation, Additive manufacturing, Spatial Visualization, Mental Rotation.
   - Answers: See Terms to Know (and use) section provided in this module. Using illustrations and demonstrations are encouraged to complete this item and is actually a higher order thinking skill should this be demonstrated.

Instructor evaluation questions:

1) At what grade level was this module used?
2) Was the level and rigor of the module what you expected? If not, how can it be improved?
3) Did the demonstration work as presented? Did they add to student learning? Please note any problems or suggestions.
4) Was the background material sufficient? Please comment.
5) Did the demonstration/lab generate interest among the students? Please explain.
6) Please provide comments on how to improve this module including concerns about the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the student):

1) Was the experimental procedure clear and understandable?
2) Was the instructor's explanation comprehensive and thorough?
3) Was the instructor interested in your questions?
4) Was the instructor able to answer your questions?
5) Was the importance of materials testing made clear?

6) What was the most interesting thing that you learned?