Hardware Store Science Curriculum

# Applications of the Design Process

ICP Maker-STEM Content Document

**Key Terms**

**Dimension** - an expressed numerical value used to define the size, location, orientation, form or other geometric characteristics of a part

**Engineering Tolerance** - allowable amount of variation in the dimensions of a machine or part

**Measurement** - the determination of the size or magnitude of something with applied units

**Orthographic Projection** – a 3D drawing of an object within a 2D surface

**Prototype** - first/preliminary model from which others are developed

**Lesson 1 – Communicating Design:** This module begins by applying the engineering design process to create a preliminary solution to a design challenge. We will begin working our way through the design process by generating design sketches based on stated challenge constraints. *(IED-1.5, 6.10, POE-5.3)*

**Lesson 2 – Modeling with TinkerCad:** Next, we will explore orthographic projections as a means of communicating design concepts to peers and colleagues. We will utilize tinkercad.com as an example modeling software to create a 3-dimension image of our sketched design solution. *(IED-1.5, 6.10, POE-5.3)*

**Lesson 3 – Extrusion 3D Printing:** Armed with and understanding of the design process, prototyping, and modeling software we will learn about 3D printing. We will discuss 3D printing applications in relation to rapid prototyping for manufacturing purposes and its application within various industries. *(IED-1.5, 6.10, POE-5.3)*

**Lesson 4 – Applied Engineering:** Finally, after modeling the steps of the design process from brainstorming to prototyping we will address the challenge of creating a toy car chassis capable of meeting immediate and future design constraints associated with the educational related needs. *(IED-1.5, 6.10, POE-5.3)*

***Module 3 Guiding Question***

**How do 3D modeling software and 3D printing provide an effective tool for engineers to develop working prototypes and models?**

## Makerspaces

A **makerspace** is a collaborative workspace that houses a wide variety of technology, tools, and resources. They typically include 3D printers, laser cutters, CNC machines, soldering irons and even sewing machines. However, if you have cardboard, Legos and art supplies you have the tools of a makerspace. The mindset of creating something out of nothing and exploring your own interests is at the core of a makerspace. These spaces provide hands on learning, help with critical thinking skills and even boost self-confidence. Some of the skills that are learned in a makerspace pertain to electronics, 3D printing, modeling, coding, robotics and even woodworking. Makerspaces have been called everything from a FabLab to a Techshop to a hackerspace. No matter the name, they are all places for making, collaborating, learning and sharing.

Although they have a lot in common, there are differences. FabLab and Techshop are trademarked names for a particular type of makerspace while hackerspace is a description. Whatever the name, each involves prototyping, innovation and space to create, providing stimulus for individuals to play, to create, to learn, to mentor, to invent.

The maker movement is about teaching and learning that is focused on learner centered inquiry. Making is not about the projects at the end of a unit of learning, but rather what takes place throughout the learning process. It's about returning to a more traditional exploratory and inquiry-based process rather than memorizing facts and formulas for doing well on a standardized assessment. Business leaders describe the need for students to graduate with the skills of creativity and innovation, and STEM related education is key to making this happen. There are essential elements of learning that require us to become innovators, completing hands-on projects where we have to solve a real problem. As we learn how to apply knowledge and content from a variety of courses to solve a problem, or to work in teams to complete a task we are able to retain and recall information more easily. This is at the heart of the maker movement manifesto - "imploring individuals, community centers and schools to allow people to make, share, give, learn, tool up, play, participate, support, and change."

Makerspace is an educational movement that takes DIY and meshes it with formal education. Makerspace is not only a hack shop where you can go to learn how to use an arc welder for the afternoon, but an educational concept and attitude. A makerspace presents readily available materials that can act as a stimulus for inquiry, as well as modern technology and resources that are not typically available at home. Makerspace is more than a space; it is a mindset that can and should be learned in this increasingly technology driven world. With a makerspace, we can move beyond swiping our finger across a screen to imagining, creating, and sharing with peers and others. We develop skills and abilities that will lead to career fields never dreamed of. All the while, providing a unique opportunity to apply the knowledge we have acquired and have fun doing it

## Lesson 1: Objectives

- **Apply the engineering design process to solve problems within established constraints and materials specifications.**

## Content

- **Brainstorming**
- **Turning ideas into images**

**Lateral -** *(noun)* a part of something growing out from the side or sides

## *Lesson 1: Communicating Design*

Brainstorming combines a relaxed, informal approach to problem solving with lateral thinking. It encourages people to come up with thoughts and ideas that can, at first, seem a bit crazy. Some of these ideas can be crafted into original, creative solutions to a problem, while others can spark even more ideas. Brainstorming is about avoiding criticism or praise for ideas and just focusing on possibilities and breaking down incorrect assumptions about the problem.


Brainstorming provides a free and open environment that encourages quirky ideas that are built upon to develop a variety of creative solutions. When used during problem solving, brainstorming brings out group/team members' diverse experience and leads to better solutions to the problems that we are trying to solve.

Brainstorming is not only useful when working in groups/teams. In fact, several **studies** have shown that individual brainstorming produces more and often better ideas than group brainstorming. Individual brainstorming does not include worrying about other people's opinions, and we feel freer and more creative. For example, you might find that an idea you'd hesitate to bring up in a group develops into something special when you explore it on your own.

However, you may not develop ideas as fully when you're on your own, because you don't have the wider experience of other group members to draw on. Individual brainstorming is most effective when you need to solve a simple problem, generate a list of ideas, or focus on a broad issue. Group brainstorming is often more effective for solving complex problems.

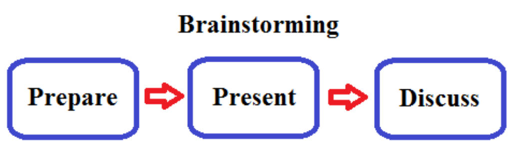
**To get the most out of brainstorming, choose a place that minimizes distractions and encourages focusing on the problem at hand**

Group brainstorming can take advantage of the full experience and creativity of all team members. When one member gets stuck with an idea, another member's creativity and experience can take the idea to the next stage. Our combined knowledge can develop ideas in greater depth than we can with individual brainstorming. Another advantage of group brainstorming is that it helps everyone feel that they've contributed to the solution and share responsibility for solving the problem/task.

We get the best results by combining individual and group brainstorming, and by managing the process according to agreed upon rules. By doing this, we can focus on the issue without interruption, maximize the number of ideas we generate, and work as a team to solve a problem or complete a task rather than a bund of individuals.

Effective brainstorming most often follows these steps.

**Step 1: Preparation**




How much information do/does you or your group need in order to brainstorm solutions to your problem? Remember that prep is important, but too much can limit – or even destroy – the freewheeling nature of a brainstorming session. Consider the strengths of each member. Try to encourage input from as many members as possible, each member will have a unique way of looking at the problem statement or guiding question.

It is important to have one member of the group record the ideas that are developed. It is hard to record and contribute at the same time so this person should not be expected to know details and will need to work with other group members to sort through possible solution specifics. Using a large sheet of paper or whiteboard will help. You could also use a computer with a projector or shared document accessible to all group members.

**Step 2: Present Problem Statement or Guiding Question**

Clearly define the problem that you want to solve and lay out any criteria that you must meet. Provide group members quiet time at the start to write down their own ideas. Then, share ideas while giving everyone a fair opportunity to contribute.

**Step 3: Discussion**

Build on the ideas presented. Encourage everyone to contribute to develop each idea, this could be either in the form of additions or critiques, but never, criticizing the idea as a whole. You can support a group member’s idea and point out improvements that add to the idea or overcome weaknesses not seen by others. Stick to one possible solution at a time and refocus the group if they become sidetracked.

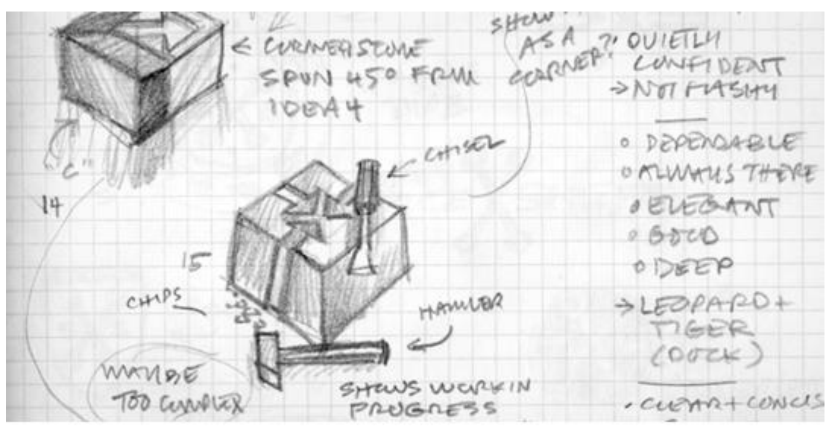
Another benefit of not criticizing ideas is increased creativity by group members. Your group will come up with more possible ideas when they feel their input matters. Don't follow one train of thought for too long. Make sure that you generate a good number of different ideas and explore individual ideas in detail. If a group member needs to "tune out" to explore an idea alone, allow them the freedom to do this.

Brainstorming and sketching really go hand in hand, as sketching is inherently brainstorming (idea generation) and brainstorming can be communicated via sketching. Sketching can help you get your brain outside of its box and on its way towards innovation. Sketching can also be helpful in capturing thoughts, exploring ideas, and then sharing those ideas.

When it comes to sketching, we need to move past “I’m not an artist” or “I can’t draw” because the artistic quality of our sketches is not the point. The real goal of sketching is about generating ideas that solve a problem and communicate our ideas more effectively with others. Sketching adds to the design process by providing a unique way to think differently, generate a variety of ideas quickly, explore alternatives with less risk, and encourage constructive discussions with group members.

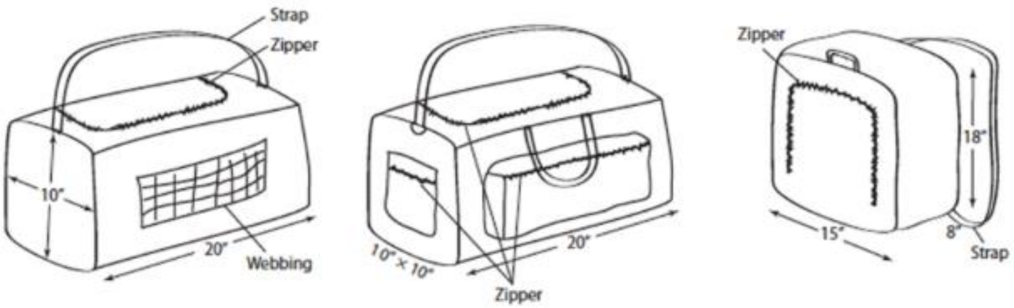
Three benefits of sketching ideas during brainstorming:

1. A variety of ideas, quickly - Sketching is great for rapid idea generation. A pencil and a piece of paper are all that is needed to generate ideas quickly and creatively. Once an idea comes to mind, I capture it on paper, add notes, and number each sketch as reference for later review. Wait until you have finished to make any judgment on good or bad.



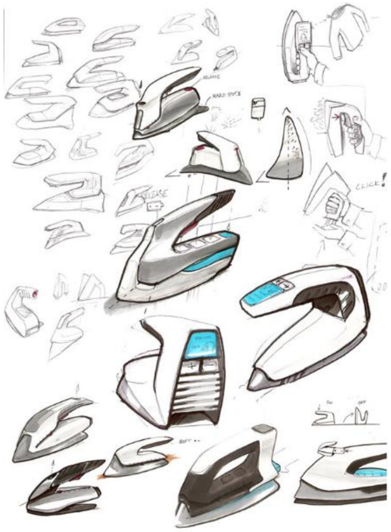

2. Exploring alternatives - Sketching offers you the freedom to explore alternative ideas. Early in a project or investigation it is important to think through different options so we can choose the best solution. Sketches help eliminate ideas that are impossible or impractical to produce. Sketching out our ideas helps reveal potential issues before significant time is invested. This is the time to ask, “what if?” and explore the answers that pop into your head.




3. Better Discussions - Sketches provide a visual of our thinking during discussions about projects and investigations. Sketches give group members the permission to consider, talk about, and challenge the ideas we represent in a way that fosters input and group thinking. Others contribute thoughts we couldn't come up with on our own.

   Doodles in the margin of activity sheets and experimental procedures will help clarify thinking when analyzing test results and experimental data. When sketching becomes a routine part of your design process you might be surprised at the ideas you will capture.



**Subset -** *(noun)* part of a larger group or related things

Give sketching a try for the idea generation and communication phases at the beginning of your next project. Remember, it's not about the quality of the drawing, but about capturing and communicating ideas from one mind to another.

Generate as many different ideas as you can. Explore crazy, way-out-there ideas and then see how members of your group react. You might be surprised at the discussion that ensues.

## *Lesson 2: Modeling With TinkerCad*

3D Modeling is used in a variety of applications to make representations of physical objects in a digital format. 3D modeling is a subset of Computer Aided Design (CAD), in which you use a computer to assist in the design process. The computer model is used to communicate such things as dimensions, material types, and even make control paths for Computer Numerical Controlled (CNC) machines.

Most often 3D Modeling makes the design process more efficient, allowing us to create and visualize final products, modify and optimize the designs, and document designs and measurements easily. Also, 3D modeling is what is used to design objects before they are 3D printed.

### 3D Modeling in Engineering

Engineers are required to flush out their ideas before they become reality, so most objects that you see around you were first designed in 3D design software by engineers

### Lesson 2: Objectives

- **Repeat 3D modeling attributes and activities to design and model a unique variation to a previously modeled 3D object.**

### Content

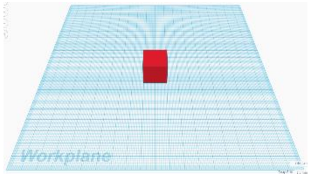
- **Tinkercad.com modeling software attributes**

before they were made. There are distinct advantages to using 3D CAD programs to design things before building them. For example, each component of your cell phone was modeled using 3D modeling software, each part's shape and cost was optimized for its use, and all of the models were put together in an assembly in the software to ensure that they all fit together properly. The files were then all sent to a manufacturer, where computer-controlled machines were able to make all of the parts, and workers used the files to follow the assembly steps to physically build the cell phone you use every day.

AUTODESK TINKERCAD

**TinkerCad can be accessed by creating a free user account at tinkercad.com**

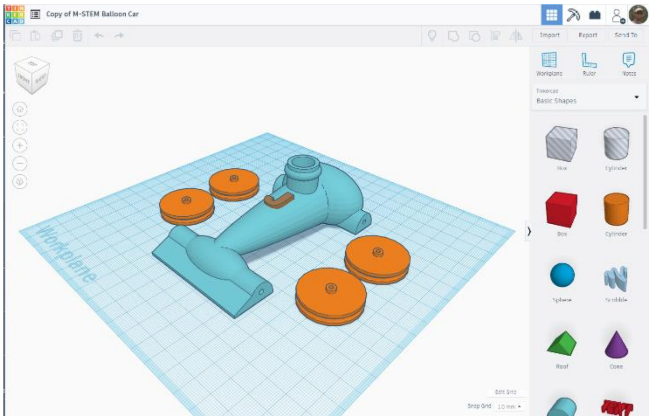


## TinkerCad

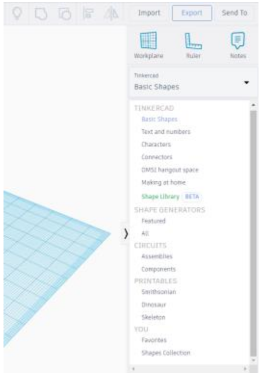
All 3D modeling programs start out with the basics of working in 3D dimensions: simple shapes and geometries. TinkerCad by Autodesk begins the design process with simple 3D shapes like blocks, cylinders, and spheres whose dimensions can be adjusted. Above is a simple box made in TinkerCad that can be manipulated to any dimension. TinkerCad allows you to modify, edit, and manipulate simple shapes to create more complicated ones, as illustrated below.

From basic shapes and commands, almost anything can be created using a variety of tools and templates that every CAD program provides. Most 3D modeling programs contain introductory tutorials so we can become familiar with the software. Some programs are a bit different than the one we will be using, but don't be alarmed; though set up differently, you will still be able to figure them out as you play around. Most 3D design software allows you to create a couple different file types, from part files to assembly files, drawings, simulations, animations, and even manufacture files.

All CAD programs have a similar design environment that allows you to view, edit, and document your design files. The file itself sits in the center of the environment, and the tools to manipulate the file are located around the edges. If you are using a modeling program other than TinkerCad, these tools may be in different places. We will go through the most common tools and things that you'll see in your window when you open up a file.

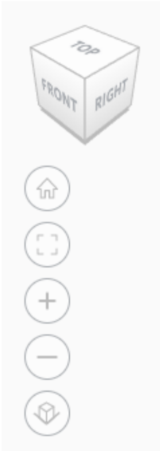


## The Toolbar



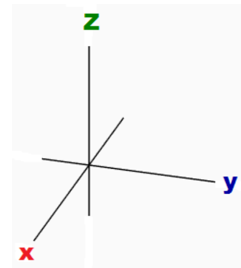
The Toolbar is a very important component of CAD software, it is what allows you allows you to actually create 3D shapes. Each section of the toolbar contains features or actions that allow you to form and edit your model. While the organization of the tools in each CAD program will be different, most of the features will be found somewhere among the tabs of your CAD program's toolbar. It may go by a different name, so you may have to search for a term within your program.

### Planes, Axes, and Points



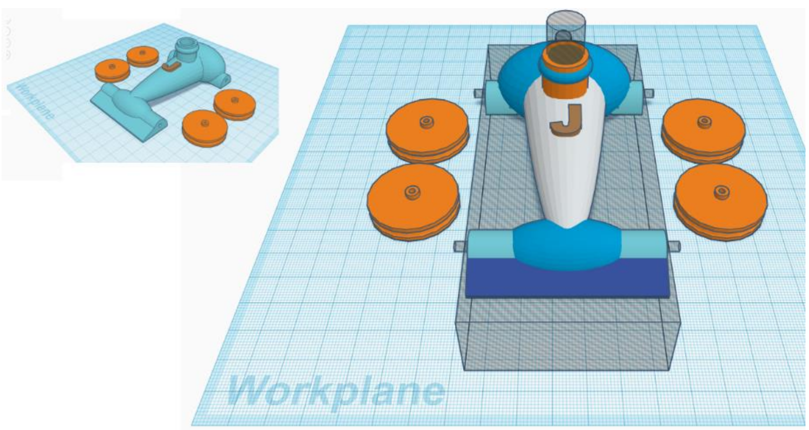

Before we start actually building things, it is important to bring up some features of 3D design software: reference geometries. These are planes, axes, and points that you can use to locate your part and its features in 3D space. All files will start out with the base reference geometries, centered around the origin, or the "zero-point", which the CAD software defines as the point (0,0,0) in 3D space. CAD programs function in a Cartesian coordinate system, so all points are defined by x, y, and z distances from the origin. The X,Y, and Z axes extend from the origin, and form the XY, YZ, and XZ planes. All of these reference geometries can be referenced in images and features when designing the part. Images and models are defined by the plane that they lie on, and the axes and the origin can be referenced to create dimensions. You can also create new planes, axes, and points elsewhere in your 3D model.

**Cartesian Coordinate System: is based on three mutually perpendicular coordinate axes: the x-axis, the y-axis, and the z-axis, illustrated below.**




### Dimensions and Constraints

When sketches are initially drawn, they are unconstrained. There are no dimensions or constraints associated with a line when it is first created, so you are free to move it around on the sketch plane. It is good practice in CAD programs to dimension and constrain your sketches appropriately so that they don't accidentally get messed up or altered. To make the shape we want, we need to use the dimension tool to make it the correct size, and the constraints to create the relationships between the length, width and height.




In TinkerCad, if objects/features are grouped together they will turn a different color to let you know that they are no longer able to move individually. While it is important to fully define your sketches when finalizing your model both to convey to others the dimensions, and to ensure you won't accidentally change something about your part, you may want to leave a model ungrouped/unconstrained so that you can play around with its size and shape and see how it affects your 3D model.

## *Lesson 3: Extrusion 3D Printing*

The term 3D printing, also known as additive manufacturing, is a technology that offers the capabilities for the production of parts and products in different materials. Essentially, it is a process for making a physical object from a three-dimensional digital model, typically by laying down many successive thin layers of a material, bringing a digital object (its CAD representation) into its physical form.

### Lesson 3: Objectives

- **Describe the steps used for the creation of a simple 3D modeled object.**

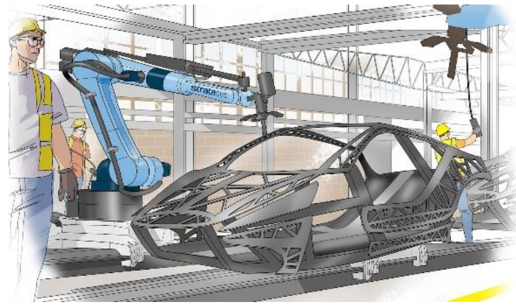
### Content

- **Introduction to 3D printing**
- **3D Printing Technology**
- **3D Printing Applications**

There are several different techniques to 3D Print an object; bringing two fundamental innovations: the manipulation of objects in their digital format and the manufacturing of new shapes by addition of material.

**Digital + Additive Manufacturing**



The most basic principle behind 3D printing is that it is an additive manufacturing process that builds up objects in layers at the sub mm scale. There are a number of limitations to traditional manufacturing, which has widely been based on human labor and made by hand. However, automated processes such as machining, casting, forming and molding are all (relatively) new, complex processes that require machines, computers and robot technology. These technologies manufacture parts by subtracting material from a larger block whether to achieve the end product itself or to produce a tool for casting or molding processes. This is an inherent limitation within the overall manufacturing process.

The subtractive manufacturing processes can result in up to 90% of the original block of material being wasted. In contrast, 3D printing is a process for creating objects directly, by adding material layer by layer in a variety of ways, depending on the technology used. 3D printing encourages innovation while reducing prohibitive costs and lead times.

The earliest 3D printing technologies first became visible in the late 1980's, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more cost-effective method for creating prototypes for product development within industry.

**Printing Technology**

The starting point for any 3D printing process is a 3D digital model, which can be created using 3D modeling software programs like TinkerCad or with a 3D scanner. The model is then 'sliced' into layers, processed by the 3D printer according to uploaded design codes and printed using ABS or PLA plastic materials. There are a number of alternatives to plastic, including metals, ceramic and sand. Research is also being conducted for 3D printing biomaterials in different types of food (sugar and chocolate).

**How it Works**

The most common and easily recognized process is extrusion of thermoplastic material. This is a process that extrudes plastics in filament form through a heated extruder to form layers and create the predetermined shape. Because parts can be printed directly, it is possible to produce very detailed and intricate objects, often with functionality built in and negating the need for assembly. However, file preparation and conversion can be time-consuming for parts that demand intricate supports during the build process.

The most common process works by melting a plastic filament which is then deposited onto a build platform according to the 3D data supplied to the printer. Each layer hardens as it is deposited and bonds to the previous layer.

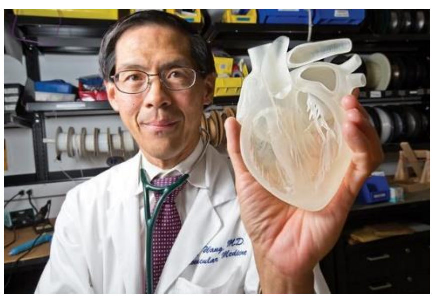
The printed piece may require support structures for any features with overhanging geometries. These can easily be removed once the print is complete. The materials available for 3D printing have come a long way since the early days of the technology. There is now a wide variety of different material types, that are supplied in different states (powder, filament, pellets, granules, resin etc.).

ABS is a common plastic used for 3D printing. It is a particularly strong plastic, comes in a wide range of colors and can be purchased in filament form. PLA is a biodegradable plastic material that can also be utilized in filament form. It is offered in a variety of colors, including transparent, which has proven to be a useful option for some applications. However, it is not as durable or as flexible as ABS.

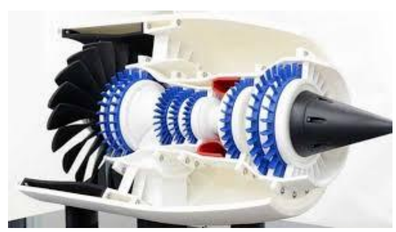
## Printing Applications

The origins of 3D printing in ‘Rapid Prototyping’ were founded on the principles of industrial prototyping as a means of speeding up the earliest stages of product development with a quick and straightforward way of producing prototypes that allows for multiple iterations of a product to arrive more quickly and efficiently at an optimum solution. This saves time and money at the outset of the entire product development process and ensures confidence ahead of production tooling.

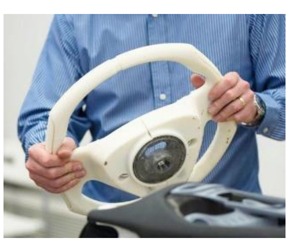
**3D printed leg**



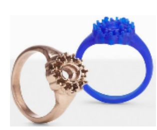
The medical sector is viewed as being one that was an early adopter of 3D printing, but also a sector with potential for growth, due to customization and personalization capabilities of the technologies and the ability to improve people’s lives as the processes improve and materials are developed that meet medical grade standards.



Like the medical sector, the aerospace sector has been at the forefront in terms of pushing the boundaries of the technologies for manufacturing applications. Because of the critical nature of aircraft development, research and development is demanding and strenuous, standards are critical and industrial grade 3D printing systems must meet these same standards.



Another general early adopter of Rapid Prototyping technology was the automotive sector. Many automotive companies are not just using the technology for prototyping applications but developing and adapting their manufacturing processes to incorporate the benefits of improved materials and end results for automotive parts. Many automotive companies are now also looking at the potential of 3D printing to fulfill after sales functions in terms of production of spare/replacement parts, on demand, rather than holding huge inventories.



For the jewelry sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest — and uptake — based on how 3D printing can, and will, contribute to new design freedoms enabled by 3D CAD and

3D printing, through improving traditional processes for jewelry production all the way to direct 3D printed production eliminating many of the traditional steps to jewelry making.

Artists and Sculptors are engaging with 3D printing in myriad of different ways to explore form and function in ways previously impossible. Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printed accessories including shoes, headpieces, hats and bags have all made their way onto global catwalks. Initial efforts into 3D printing food were with chocolate and sugar, and these developments have continued with the development of specific 3D printers including the 3D printing of "meat" at the cellular protein level.

## Lesson 4: Objectives

- **Execute the engineering design process from conception of idea to 3D printing of prototype model**

## Content

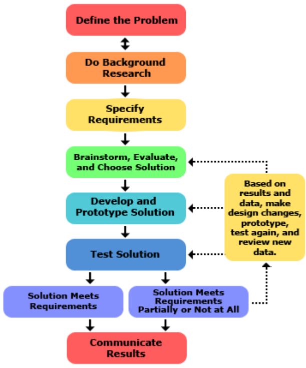
- **Engineering Design Documentation**
- **Design Requirements**
- **Research and Storyboarding**
- **Prototype, Test, Redesign**

***Lesson 4: Applied Engineering***

The steps of the engineering design process followed to come up with a solution to a problem involve more than brainstorming, modeling, and 3D printing prototypes. Designing solutions that meet certain criteria and/or accomplishes a certain task is different from the Steps of the Scientific Method, which you may be more familiar with. If the activity only involves making observations and doing experiments, you should probably follow the Scientific Method. If the activity involves designing, building, and testing something, you should probably follow the Engineering Design Process. If you are unsure which process to follow, you can refer to the diagram on the next illustrating a more detailed Engineering Design Process. This diagram shows a more accepted set of steps engineering actually go through as they apply the design process within their career field.

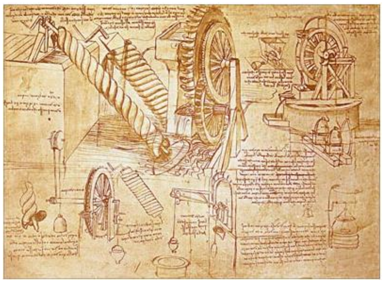
Engineers do not always follow the engineering design process one after another. It is common to design something, test it, find a problem, and then go back to an earlier step to make a modification or change in their design. This way of working is called **iteration**, and we will use this process as we make improvements to designs, investigations, and projects.

**Iteration -** *(noun)* a procedure in which repetition of a sequence results in improved results




**A chart comparing the scientific method and the engineering design process can be found in the Experimentation Through Design module**

A design notebook is a way for a designer or engineer to keep a history of his or her design project from start to finish. It is a place to record research, observations, ideas, drawings, comments, and questions during the design process. At the end of a project, a review of the design notebook should result in a full understanding of how we got our solution. Let's take a closer look at each step.



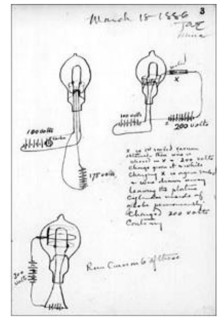
### 1. Define the Problem

The engineering design process starts when we ask the following questions about a problem we observe.:

- What is the problem or need?
- Who has the problem or need?
- Why is it important to solve?

These can be summarized as - [Who] need(s) [what] because [why].

There is never a predetermined time limit to the design process. Similar to scientific investigations, the design process takes days, weeks, sometimes even months or years, to complete and involves many different steps and phases along the way. If we recorded all of our work in different places, it would be almost impossible to find important thoughts when we need to refresh our memory and present our solutions. To avoid being disorganized, designers and engineers keep design notebooks in the same way a scientist records details of their experiments with slight differences.



Just like keeping a lab journal everything goes in a design notebook during a design project. A project starts when we begin thinking about possible solutions to the problem. Begin by writing down everything you know about the problem and why it needs to be solved. Then write down, draw, sketch, glue, or tape in every step of your process between this first step and your final solution, examples include:

- Notes on background research
- Interviews with users or experts
- Drawings and sketches
- Photos of competing products
- Lists of design requirements
- Questions/issues you face

### 2. Do Background Research

Learning from the experiences of others helps us avoid the mistakes they made in the past. Begin by doing background research on existing solutions. No matter how you do your background research, record your sources and take good notes as you go. A good reference resource will go a long way in supporting your solution and help refine your thinking.

| Reference Checklist |
| --- |
| Does the reference come from a credible source |
| Is reference current |
| Is reference objectively written, not biased towards one point of view |
| Is reference error free |
| Does reference properly cite the original source of all information |
| Is reference easy for other people to find or obtain |

Often the best place to start your background research is by searching keywords. Once a reference is found, you can look at the sources cited in the bibliography for other references. By using this technique of routinely following up on sources cited in bibliographies, you can generate a surprisingly large number of books and articles on your topic in a relatively short time.

If you are finding too much information, for example pages and pages of irrelevant hits on Google or a periodical index, you need to narrow your search. You can narrow your search by borrowing some of the terms in your research questions. For example, let's imagine that searching on "milk" brings up too much irrelevant information about cows. Try searching milk composition or milk properties characteristics. This will narrow your search, and hopefully give your more relevant results.

If you aren't finding enough information, you need to simplify your search. Let's imagine that searching on "measuring spiciness" isn't finding what you want. Try searching measure spiciness, spiciness, or spice. Most online search engines and periodical guides have helpful instructions about how to narrow and broaden searches. Sometimes the information you find will be relevant, but either too complicated given your science background or too babyish. Be sure to collect information you understand and will answer the research questions fully.

### 3. Specify Requirements

Design requirements state the important characteristics that our solution must meet to succeed. One of the best ways to identify the design requirements for our solution is to analyze the concrete example of a similar, existing product, noting each of its key features.

For example, imagine that your problem statement relates to grocery store bags. You want to design a better grocery store bag; one that uses less expensive material than the paper and plastic bags that already exist. Your design requirements are the important characteristics that your bag must meet to be successful. Based on your problem statement, a successful bag would use less expensive material than existing bags and function properly as a grocery bag. Examples of some of your design requirements might be that the bag needs to:


- Have handles so that shoppers can carry multiple bags of groceries.
- Hold up to five pounds of food without breaking.
- Cost less than five cents to make.
- Collapse so that it can be stored in large quantities at grocery stores.

Effective design requirements are *needed* to solve your design problem (If it is not needed, leave it out) and *feasible* (you have the time, money, materials, tools, and knowledge to make it happen).

Analyzing existing products, helps us build a mental library of techniques, mechanisms, and clever tricks to use when constructing our own designs.

### 4. Brainstorm Solutions

There are always many good possibilities for solving design problems. If we focus on just one before looking at the alternatives, it is almost certain that we are overlooking a better solution. Good engineers try to generate as many possible solutions as they can.

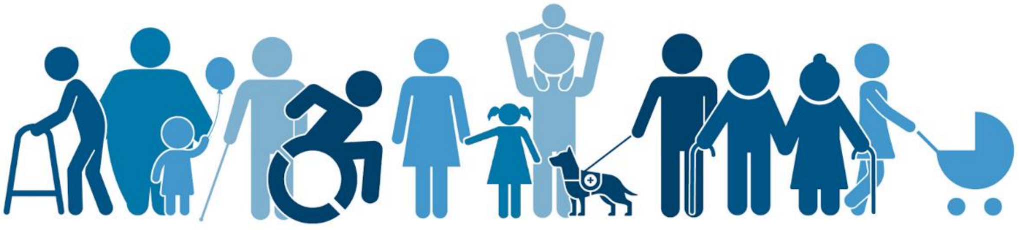
### 5. Choose the Best Solution

Once you have created a number of possible solutions to your design problem, you need to choose which one is best. This can be done by looking at whether each possible solution met your design requirements. Consider solutions that did a better job than others and reject those that did not meet the requirements.

In addition to your design requirements, you probably have some features that would be "nice to have" in your solution. These are things that are not quite as important as your design requirements; they are desirable, but not mandatory. Some of your possible solutions might include more of these nice-to-have features than others, and that makes for meeting the designation of best.

#### Universal Design Criteria

Some criteria apply to virtually every design. Good designers consider them in every solution that they choose to implement.



- **Elegance.** An elegant design solution is simple, clever, or ingenious. It might have fewer parts to wear out or fail. It might combine solutions from different areas in an inventive way not seen before.
- **Robustness.** A robust design is unlikely to fail, even when used in conditions more severe than it was designed for. It is sturdy or resilient, perhaps bending, but not breaking in hard use.
- **Aesthetics.** If everything else is equal, people prefer a solution that is tasteful and pleasing to look at.
- **Cost.** What will it cost? Can you afford the solution?
- **Resources.** Do you have the resources to build a working prototype, or will you be able to obtain them quickly?
- **Time.** Do you have enough time to complete your design and make it before the due date? Don't forget to allow time for additional research and fixing problems.
- **Skill Required.** Do you have the skills to build your solution, or can you learn them in the time available?
- **Safety.** Is your solution safe to build, use, store, and dispose of?

If your requirements and solutions are relatively simple, you can sometimes just list the pros and cons for each solution. Pros are good things about a solution and cons are bad things.

### 6. Develop the Solution

Development involves the refinement and improvement of a solution, and it continues throughout the design process, By creating a storyboard, we can break down the project into more specific components over time, which allows us to analyze it more closely. Storyboarding is helpful during research, prototyping, and during presentations.

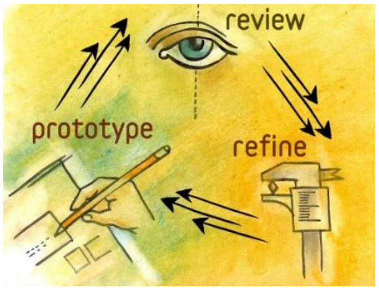
Once you have completed creating possible designs, you are going to have a list of possible ways to solve your problem. Take each solution and draw it out. Create a storyboard that shows how to interact with each design solution. Break down and draw out how the solution overcomes the problem, comparing storyboards will help determine which solutions may be better than others.

### 7. Build a Prototype

A prototype is an operating version of a solution. Often it is made with different materials than the final version, and generally it is not as polished. Prototypes are a key step in the development of a final solution, allowing the designer to test how the solution will work.

### 8. Test and Redesign

The design process involves multiple iterations and redesigns of our final solution. We need to test our solution, find new problems, make changes, and test new solutions before settling on a final design.




The goal is to test our solution, find the problems and make changes, test the new solution, find new problems and make changes, and so on, before calling the project complete. Minor changes in the design process can make or break our solution, so it is important to be thorough in our testing.

When it comes to testing, there is no such thing as too many tests. The more you are able to test the more you will find out. A good goal is to go through three to five cycles of test trials.

After you have tested your design, you will use your findings to complete a redesign of your solution. Use the findings from testing to fix any problems that occurred, and further polish aspects of the design that were even more successful than you originally thought. There are four major questions we can asked during testing that will help when it comes to redesigning our solution

1. Is the solution able to overcome the problem? If the answer is "yes," focus on why the solution was successful. Consider emphasizing these aspects of your design. Then, in the next round of testing, see if the new version is able to achieve success even more quickly and easily. If the answer is "no," focus on the problems encountered during testing. What prevented the solution from achieving success? What changes to your design would eliminate these issues?
2. Are all requirements met when using or interacting with the solution? If the answer is "no," focus on the requirements not met. What part of the solution didn't meet the requirements?
3. Does the solution work exactly the way that you intended it to? If the answer is "no," focus on what you hadn't intended to happen. Did the unexpected results make your design more successful or less successful? If less successful, what changes could you make to your design to prevent these unexpected actions?
4. If you have measurable targets for your solution, did you meet them? If your design requirements call for your solution to be better, faster, or cheaper, you should measure the improvement that you made. If not, how can you redesign your solution to improve its performance?

Once you have made changes to your design, go back and test again. See if the improvements and changes you made negatively or positively affected your solution. Ask yourself the same set of questions, and then repeat the redesign again. Repeat this test and redesign process as many times as necessary to make your final solution as successful as possible.

### 9. Communicate Results

To complete your project, communicate your results to others in a final report and/or a display board. Professional engineers always do the same, thoroughly documenting their solutions so that they can be manufactured and supported.

# Module 3 Activities and Resources

**Lesson 1:** Modeling Translational Motion Student Activity Sheet

**Lesson 2:** Orthographic Projections Student Activity Sheet

**Lesson 3:** TinkerCad and 3D Modeling Student Activity Sheet
Prototyping With 3D Printers PowerPoint Slide Deck

**Lesson 4:** MSTEM Accel Car 3D Modeling Activity Sheet

**For Educational Purposes Only**

The material contained in this document is organized and arranged to go with the MSTEM Hardware Store Science curriculum. The information is synthesized from numerous digital resources and its sole purpose is to determine the educational content resource appropriate for the associated curriculum. The material is not to be used for monetary gain.

The following is an incomplete list of referenced resources

https://www.core77.com/posts/52948/Why-is-Sketching-Still-Important-To-Design
https://www.instructables.com/Intro-to-3D-Modeling/
https://3dprintingindustry.com/3d-printing-basics-free-beginners-guide/
https://www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-process-steps

The Purpose behind all resources within the hardware store science curriculum is to research the effective integration of STEM subjects into a physical science classroom. All material is organized from outside sources and solely intended to provide the researchers a framework for the development of original content based on experimental findings.