IDAHO EXHIBITION OF IDEAS
10-WEEK TEACHING GUIDE

OVERVIEW

This guide outlines a process for educators to teach students the fundamentals of 3D design and fabrication and support those students in completing a 3D printed project for the Idaho Exhibition of Ideas (IDX) Student Showcase. Please note this document is intended as a tool for educators, not a definitive procedure your students must follow to participate or succeed at IDX. It is designed to be completed over 10 class/program sessions; however, you may choose to spend more or less time on different phases of the project based on your students' skill levels and the complexity of their design.

Students who already have some experience with 3D design may be able to skip one or more of the foundational lessons in Part One. Conversely, educators interested in teaching 3D printing in the classroom outside the context of IDX may find the foundational lessons helpful.

We have also highlighted several opportunities throughout the progression for further exploration where time allows.
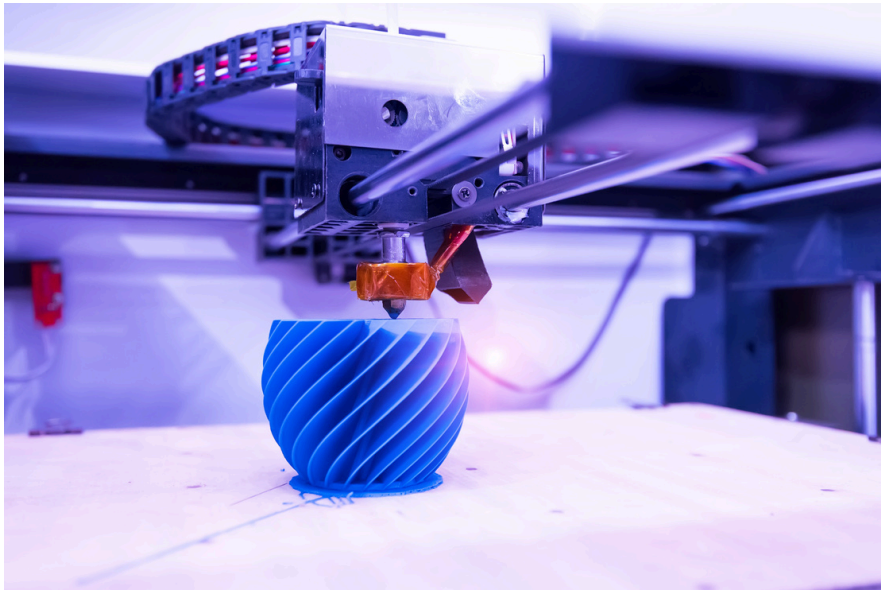
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PART ONE: FOUNDATIONS IN 3D DESIGN

The activities in Part One are designed for students with no prior experience with 3D printing or design; however, they are also useful for reinforcing key concepts with experienced students.

Session 1: Introduction to 3D Printing

Start by introducing the concepts of 3D printing and computer-aided design (CAD) to students. Invite a discussion by asking students to share information or impressions they already have about 3D printing. You may choose to have students organize this information into a schema map or similar style chart.

Then, provide a brief overview of 3D printing technology and its possibilities and limitations as a manufacturing method. Below is a list of resources related to this topic. Have your students explore one or more of these resources as a class or individually (this could be done as a homework assignment prior to class), or use them to inform your own presentation:

- Video - University of Cambridge Institute for Manufacturing, "What is 3D Printing?" (all ages)
- Video - Nat Geo Kids, "How 3D Printers Work" (grades 4-6)
- Video - VICE News, "3D Printing is Changing the World" (grade 8 & up)
- Article - Ultimaker, "What is 3D Printing - Sections 1-4" (high school & above, the first four sections provide a solid introduction, the rest could be assigned as optional)
- Article - Ultimaker, "The Future of 3D Printing: Will it Change Your Industry?" (high school & above, good hook for students who already have some exposure to 3D printing)

Group Activity: The 3D Printing Workflow (15-20 minutes)
Objective:
Students gain a deeper understanding of the 3D printing workflow through reasoning out the correct sequence of steps in the process.

Materials:
- Definitions from the 3D Printing Workflow Activity Sheet (p. 31), enlarged and printed on separate sheets of paper (option to laminate for reuse) → one set per student group

All 3D printing projects go through some variation of the 3D printing workflow -- the process of transforming an initial design concept into a final 3D printed product. The graphic below provides an overview of this process.

Procedure:
Use the definitions on the attached 3D Printing Workflow Activity Sheet. Enlarge and print each definition on a separate piece of paper. You may wish to differentiate between phases and their outcomes using two different shapes, such as the circles and arrows in the graphic above. Do not number the phases. Place students in small groups of 2-3 and provide a set of definitions (mixed up) to each group. Give students 5-10 minutes to put the phases in the correct order. Have them share their proposed order with another group. If discrepancies arise, groups must explain their reasoning behind placing a phase or outcome where they did. Finally, review the correct workflow as a class.

Additional Resources for Educators:
- Article - BCN3D: "Discover the full walkthrough of the 3D printing workflow"
- Video - Idaho STEM Action Center: "The 3D Printing Workflow"

Research Activity: Contemporary Applications of 3D Printing
Objective:
Students apply internet research skills to identify timely, real-world applications of a technology used in class.

Materials:
- Student devices with internet access

Procedure:
One of the most exciting things about 3D printing technology is that it's changing every day. Invite students to research these applications in class or as a homework assignment.

To focus their search, require examples to be from within the last three years and assign students different application areas such as transportation, medicine, sustainability, or space exploration.

If completing this unit within a particular class, you can also invite students to research applications related to the subject matter (e.g., researching applications in historical preservation for social studies class). Padlet, Wakelet or other curation platforms may be used. Or have a representative from each group give a brief summary of their findings to the class.

> ****Educator's Note:**
> If your class uses a framework for evaluating the credibility of sources online, this is a good time to remind students to apply those skills -- not everything they see, read or hear about 3D printing on the internet is necessarily true. If you're looking to start this conversation with your students, check out these resources from the University of Kansas, or this video playlist from Crash Course.

Optional:
After students share their findings, as a class, take a look at the News Page for 3DPrinting.com, which may offer some additional examples -- or have students bookmark this page for research later on.

Session 2: Understanding 3D

Before completing any Session 2 activities, each student will need to have an individual account in Tinkercad. Instructions for setting up a class in Tinkercad and adding students can be found here. Session 2 activities use Tinkercad as a tool for visualizing 3D shapes in digital space; therefore, no prior skill building in the software is needed – basic tutorials are available from Tinkercad, found here. Students will complete Tinkercad design tutorials in Session 3.

Prior to beginning any design work in 3D, you will want to establish a foundation with your students about what it means for something to be "three-dimensional" and the different conventions for describing, measuring, and orienting 3D objects in space. Below is a sequence of activities you can do with your students to help establish this foundation. We suggest you complete these activities in the order in which they are listed. Skip or adapt as needed to your students' ability levels and the amount of available time.

Group Activity: Differentiating 2D and 3D (5-15 minutes)

Objective:
Students correctly differentiate between 2D and 3D shapes and their properties and can articulate what is meant by "three-dimensional," and by extension "3D printing" and "3D design."

Materials:
- Scrap paper, chart paper or whiteboards
- Pencils, markers or dry erase markers

Procedure:
As a class or in small groups, make a T-chart that differentiates 2D and 3D shapes, drawing from students' prior knowledge of the topic. Synthesize information from different students/groups and supplement with information from the sample chart below. The complexity of the list items will vary depending on your students' ages and current math knowledge. Particularly if you do not work with these students in a math context, this will be an opportunity for you to gauge their understanding of these topics.
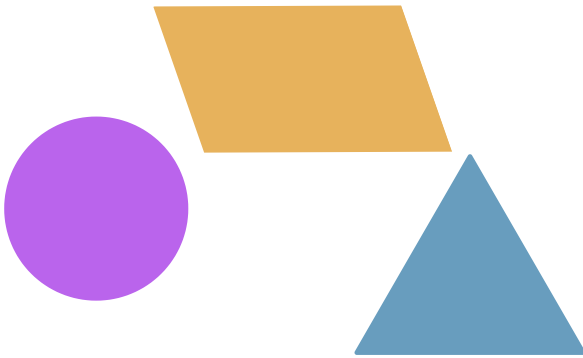
2D SHAPES

- 2D shapes are flat
- 2D" is an abbreviation of "two dimensions" -- length and width
- A 2D shape is also known as a plane figure
- We sometimes identify 2D shapes by their number of sides and vertices, however shapes with no straight sides (such as a circle or oval) have zero sides and zero vertices
- Regular plane figures we recognize include square, circle, triangle, rectangle, trapezoid, parallelogram, etc.
- Some different ways we measure 2D shapes include: length, width (or side length), perimeter & area
- Length, width and perimeter are linear measurements, but area is a 2D measurement. These two types of measurements have different types of units (inch versus square inch)
- A graph with an x and y axis is an example of 2D
- There is no such thing as a 2D object
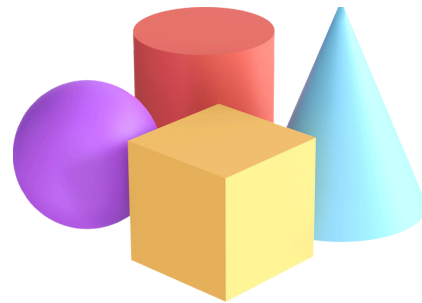
3D SHAPES

- 3D shapes are solid
- "3D" is an abbreviation of "three dimensions" -- length, width, height (sometimes depth is used in place of one of these terms)
- We sometimes identify 3D shapes by their number of faces, edges & vertices, however, shapes whose entire surface is curved (like a sphere) have zero faces, zero edges & zero vertices
- The faces of 3D shapes are plane figures (2D shapes)
- Regular 3D solids we recognize include cube, rectangular prism, sphere, cylinder, triangular prism, square pyramid, triangular pyramid, etc.
- Some different ways we measure 3D solids include surface area & volume
- Surface area is a 2D measurement, while volume is a 3D measurement, so these two measures have different types of units (square inch versus cubic inch)
- 3D space has three axes: x, y & z
- All objects are 3D -- even objects we think of as "flat" have some height/depth

Activity: Transforming 2D into 3D (25-.5 minutes)

Objective:
Students understand one method for 3D fabrication, which involves transforming a 2D image into a 3D object by adding depth and can replicate this process manually (pipe cleaner overlay) or digitally (SVG import to 3D print).

Materials:
- Pencils - one per student
- Rulers - one per student or for each table to share
- Black permanent or washable markers - one per student or for each table to share
- Blank white sheets of paper, half sheet or full size - one per student
- Pipe cleaners -- any color, miscellaneous lengths are fine
- Scissors - one per student or for each table to share
- Student laptops or Chromebooks connected to Internet
- Teacher device to take photos with OR a scanner

Educator Set Up:
Prior to the activity, set up a simple "photography station" in a clear, well-lit area on your desk. Use natural light, or supplement with a desk lamp to ensure the area is free of shadows. (If you have time, try converting a test photo to a .svg to check for shadow lines.) Have a device ready with which you can take pictures and quickly upload to your Learning Management System, as necessary. Alternatively, you can use a scanner.

Procedure:
Have each student make a simple line drawing on a piece of blank white paper. Students should make their drawings in pencil first, then trace over them with the black marker. Provide the following guidelines to students for their drawings:
- The drawing should be no bigger than 3 inches by 3 inches -- have students verify this with a ruler.
- Keep it simple (see examples below)
- All the lines in the drawing must be connected-- no loose line segments!
- Lines should be crisp, clean and dark -- if necessary, the teacher can go over the student's pencil drawing with the marker

Examples of ACCEPTABLE line drawings:

Examples of UNACCEPTABLE LINE DRAWINGS
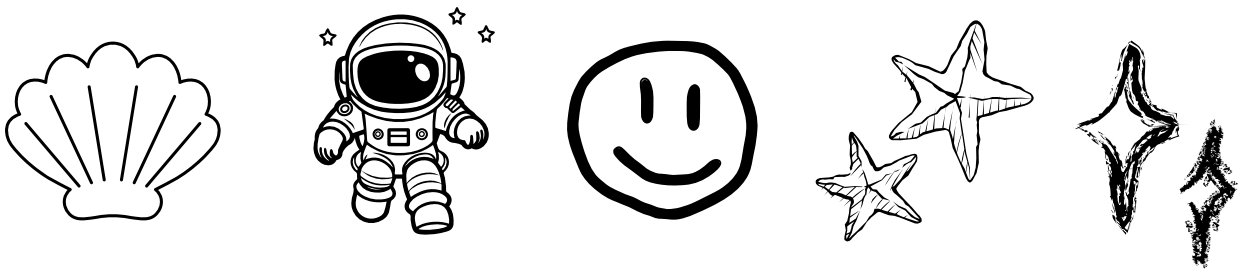
If you have students who are apt to push these boundaries, consider adding additional constraints, such as the drawing must be completed in 30 seconds or less, straight lines only, etc. You can also specify a category of simple items such as "draw me a cloud," or "draw a polygon you know."

Pose the question to students of how we might take a 2D object like your drawing and make it three-dimensional. This question is meant to spark discussion and you can take multiple answers before directing students to the idea that currently the drawing only has two dimensions -- length and width, and we need to introduce the third: height.

Explain to students that they will first introduce the third dimension using physical materials. Pass out a selection of pipe cleaner pieces to each student or table. Have students cut pipe cleaners to length and overlay them on their drawing, connecting the segments by twisting them together at the ends.

Once completed, students should measure the height of their pipe cleaner creation to demonstrate that it now has a third dimension. The height will be small, but not negligible. Remind students that all objects in the physical world have three dimensions, no matter how small.

Students will now transform their 2D object into 3D digitally. Generate a digital image of each student's drawing, either by taking pictures at your photography station or with a scanner. (Older students who have access to their own device may take their own photos; make sure they do so in a well-lit area with no shadows.) Once photos/scans are taken, share each student's image file with them. Each student will now need access to a computer. Direct students to an online image file converter such as [Convertio](#), where they can convert and save their image file as a scalable vector graphic or .svg file. Students should name the .svg file something recognizable and note the location it is saved on their device.

Students next navigate to Tinkercad and sign into their accounts. Have students create a new design, select "Import" from the upper right corner and select their saved .svg file for import. At this step, a dialogue box will appear with a preview of the shape dimensions. Look at these dimensions and verify they are no bigger than 200 x 200; if you need to make it smaller, adjust the scale down from 100. Once the .svg files are successfully imported, you can have students practice manually scaling the image according to parameters you specify, including for the height of the 3D piece, which will default to 10 mm. Once items are scaled, they can be exported as .stl files for printing or incorporated into other 3D designs.

Depending on the size of the group and whether or not you plan on introducing your students to the slicing software, this is a good "first print" to walk students through basic settings within the software and the process of transferring a file to the printer, OR introducing whatever norms you plan to use in your classroom for preparing a print (e.g. file naming conventions, how the .stl file gets to the teacher, etc.)

**Alternative Approach: Give the class an independent assignment and have students work with you one at a time to convert the image file, load it into your own Tinkercad account and prepare for printing. This may work better if you don't have time to set up individual Tinkercad accounts and/or if students need more guidance in the process.

Activity: Looking Closely at a 3D Object (20-25 minutes)

Objective:

Students are able to render a 3D object as a 2D image using the process of orthographic sketching. Students understand that a 3D object must be examined from multiple angles in order to have a complete picture of the object and its dimensions.

Materials:

- Pencil (one per student)
- Graph Paper
- Ruler (one per student pair)
- Miscellaneous objects from around the classroom

Procedure:

Divide students into pairs. Each pair should select a random object from around the classroom -- the shape of the object should be more complex than a recognizable 3D solid (i.e. no spheres, cylinders, prisms, etc.) but not so complicated that drawing it will be difficult. Think staplers, bottles, computer mouses, flashlights etc. You can also gather a selection of such items ahead of time and distribute them at random.

Have each pair spend 3-5 minutes observing their object's shape. Is it thick or narrow? Is the surface even or textured? Is it hollow? Is the top the same as the bottom? How does the shape differ depending on what angle you observe it from? What are its component shapes? Provide some example observations with an object of your own. You may have them record their observations on a piece of paper or simply discuss with one another.

Next, explain to students that they will be making an orthographic sketch of their object. An orthographic sketch uses different 2D views to give a complete picture of a 3D object. They will be responsible for drawing their object from the front, the top and the side. Show an example of what this looks like with your demonstration object. Drawings do not need to be exactly to scale, but students should make an effort to approximate as best they can.

Depending on students' ages and comfort with the assignment, you can stipulate from the beginning that relevant dimensions of the object be measured and labeled or wait until initial drawings have been made. Ask students to consider what information they would need to make an exact replica of the object before them. What if they had to tell someone this information over the phone? Ask them to measure and include in the drawing all the dimensions they think they would need. Circulate and support students as needed. If necessary, prompt with what dimensions they might normally look for in math class (length, width, height). Then ask if those dimensions are the same throughout the shape (e.g., a bottle has a different width at the top than the bottom).

Have students compare their drawings with their partners and see if they thought the same information was important. If time, have a brief discussion as a class about what they noticed or realized during this process.

Activity: Exploring 3D Solids (20-30 minutes)

Objective:
Students have a shared vocabulary for regular 3D solids and understand how they function as "building blocks" for designs in Tinkercad.

Materials:
- Several sets of 3D Shape Manipulatives like these
- Student laptops or Chromebooks connected to Internet
- Every student needs something to write with and a notebook or scrap paper

Procedure:
Place students in groups. Give each group a set of 3D solids to explore. Ask students to write down the name of each shape (if they can't recall the "mathematical" names, have them reason out an alternative, e.g. "box" for cube, etc.). They should also make note of each shape's basic properties, i.e. the number of faces, vertices, edges, whether each shape is symmetrical, or any other attributes they find interesting.

Next, provide a few examples of real-world objects that are irregularly shaped -- these could be items from around the classroom, photos of famous landmarks, etc. -- and ask how they would build the object out of basic shapes. This is an activity that your students will all have done in childhood; however, ask them to approach it with a new perspective. What are the limitations of building in this way? How could they get around those limitations? Introduce a 3D object that has "negative space," such as a container. What would be needed to create something like that? Students may volunteer answers such as "cut a hole out," to which you can respond: "What shape would that hole need to be?" This makes a great transition into the design methodology of Tinkercad.

Students can now be invited to sign into their Tinkercad accounts. Have them create a new design and then examine the panel of Basic Shapes in the sidebar. Have them explore these shapes digitally by dragging them into the Workplane and looking at them from different angles. What do they notice about these shapes as compared to the physical solids they examined earlier? They may notice that some of the shapes have "mathematical" names while others do not, or that some of the items are really the same basic shape but angled or stretched in a different way. Some students may transition naturally into trying to combine shapes or explore different features of Tinkercad; allow this experimentation as a precursor to the formal tutorials they will do in the next session.

Session 3: Introduction to Tinkercad

Objective:

Students will spend this entire session completing self-guided tutorials in Tinkercad, at their own pace. Every student should be working on their own device; however, you may wish to assign students "design partners," with whom they can discuss their process. If students get stuck, encourage them to work with their partner to figure it out, prior to asking you for help.

During this session, the educator should circulate, making sure students are staying on task and providing assistance as needed. Ideally, you should complete the assigned tutorials on your own in the days or weeks prior to this session, so that they are fresh in your mind, and you are familiar with the places where your students might get stuck.

Materials:

- Student devices: Students will need a computer, laptop or Chromebook with access to the internet. Ideally, each student should also have a mouse. Tablets are acceptable if they are also equipped with a mouse; however, having both a mouse & keyboard is best.

Procedure:

Have each student log into their Tinkercad account. Direct students to the "Let's Learn Tinkercad" series (this can be accessed via link, or by clicking Learn >> Projects and selecting from the list).

Once students complete all five lessons in the series, they can be invited to try the Table Clip Challenge (p. 32). If your students already have experience with 3D design, but you're looking to provide them with a refresher OR an introduction into user-centered design, take a look at the Intermediate Table Clip Challenge (p. 33)

If you have more time to spend on foundations in 3D Design, we recommend providing continued opportunities for skill building in Tinkercad. Options include:

- Inviting students to reiterate their table clip design based on peer/teacher feedback and/or printing and testing
- Advancing from the Beginner Table Clip challenge to the Intermediate
- Choosing a Tinkercad Lesson Plan for students to complete

PART TWO: RESEARCH AND DESIGN (BEGIN IDX PREP)

Session 4: Introduce Design Challenge

For this and all sessions going forward, **a structure should be introduced for students to document their progress in the design process**. For example, a single team member could be chosen as the *Documentation Specialist*, or this could be a rotating role. You could also create individual reflection sheets that students complete at the end of each session, that are later compiled for the slidedeck and presentation. Documentation should focus on capturing the following information: what happened that day, what decisions were made, what problems arose and how those problems were solved.

Photos and videos are a key aspect of this process. We recommend creating a shared drive folder ahead of time that all team members can access where media is uploaded at the end of each week. Similar to assigning a team member as a Documentation Specialist, you could assign another team member as the photographer/videographer, or this could be a rotating role.

As a group, review the challenge materials and prompts. The focus for the students at this point should simply be absorbing information and noticing what stands out to them, personally and as a team/class. Have students journal, or discuss as a group, their answers to a few basic prompts, such as:

- Which challenge topic area(s) do you find most interesting? Why?
- What did you learn that you didn't know before?
- What questions do you have?

After this initial information processing, students can be invited to look closer at relevant resources and begin to extract possible problems to solve.

Group Activity: Challenges & Opportunities

Objective:

Students capture insights from research materials that help them to define a design problem for the IDX Showcase.

Materials:
- Paper or sticky notes
- Pens/pencils

Procedure:

Divide students into groups (if working with a large class) or allow students to work as individuals/pairs (if working with a smaller team). Assign each group or person a topic area to focus on. You can also allow students to choose the topic that is most interesting to them (based on their journaling exercise from earlier); however, be aware if the entire class is gravitating toward the same topic. Consider asking for volunteers to be part of a special "Contingency Team," who will investigate a backup option in case the preferred topic does not inspire enough ideas. (This is a strategy you may come back to multiple times during the design process.)

Have students review resources related to their selected topics. (This may include resources suggested for the Showcase, as well as those curated by the educator, students or both.) On a piece of paper divided in half, or on two different colored sticky notes, they should make note of *challenges* that come up in the research material, as well as potential *opportunities*.

Sample Topic Area: ATV Safety

CHALLENGES
- Getting snowbound in winter
- Dehydration in summer
- Riders who don't wear helmets
- Breaking down or running out of gas in areas with no cell service
- Avalanche risk

OPPORTUNITIES
- Getting high-centered or stuck in a hole
- Emergency equipment that could also make the ride more comfortable in a non-emergency
- Capturing cool video footage or data for research that could also be broadcast in case of emergency
- A way to get unstuck you could also use for your car

In the last few minutes of the work session, have students/groups that were working on the same topics pool their notes, then give students the chance to look at all the different data together. Notice if certain topic areas yield more insights than others. If possible, leave the data up in a visible location between now and the next session, so that students can continue to review and ruminate. You can also leave out a pad of sticky notes and a marker so students can add to the data between sessions.
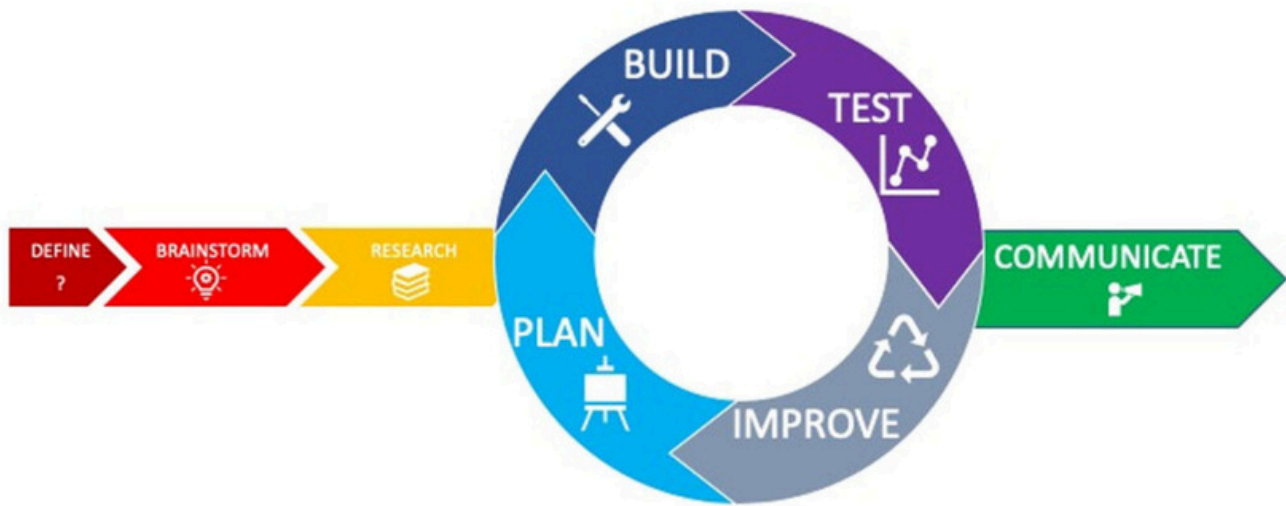
Session 5: Brainstorm

At the beginning of this session, students will identify 2-3 Challenges/Opportunities from last time to brainstorm around -- these will be the defined "problems" they are seeking to solve. If working with a smaller team of students, the team can decide together which problems to focus on. If working with an entire class, this is the point at which students should be separated into their formal "design teams," with whom they will work for the remainder of the project. Recommended team size is 4-6 students. Each of these teams can then decide for themselves which problems they would like to tackle. We recommend limiting teams in the classroom setting to 2 design questions a piece, so that everyone has the same amount.

Once problems are chosen, the team(s) should work on rephrasing each problem as a question, for which the answer is the design solution they will create. It can be helpful to start this question with the phrase: "How might we... ?" For example, if the problem chosen from the Sample Topic Area above was "Riders who don't wear helmets," the question might be "How might we create a device that encourages ATV riders to wear their helmets?" If students are struggling to come up with the right question, ask them to think about how they want the situation they have identified to change. To the problem of ATV riders not wearing helmets, you might ask: "Well, what do you want the riders to do instead?" "Wear their helmets." "Ok, what can we build to make that happen?"

The educator can offer feedback as needed to ensure questions are appropriately specific and genuinely address the problem at hand. Help students to focus on aspects of a problem that are actually solvable; if they are focused on ATV riders getting snowbound, for example, it is not feasible to seek solutions to stop the snow, but rather how to keep someone safe should this event occur. For the purposes of the Showcase, you should also make sure questions refer to a physical object that can be created or modeled with the 3D printer. (Remember, however, it does not have to be something that's final form would necessarily be 3D printed.) Once design questions are finalized, each team should further divide into pairs. Each pair should complete the following two exercises with one of the group's chosen Design Questions.

Activity: Identify Constraints & Criteria for Success (15-20 minutes)

Objective:

Student team(s) use research materials to identify constraints and criteria for success around several potential design questions for the IDX Challenge.

Materials:
- Paper/sticky notes or whiteboard
- Pens or pencils
- At least one device per team of 2-3 students, for research purposes

Procedure:

At the top of a large piece of paper or whiteboard, students should write the design question they are addressing. Based on evidence they can point to in the research material, they should now make two lists.

First: A list of **Criteria for Success** -- things the design needs in order to be successful. What requirements does it need to fill? What features or functions must it have? Whose needs must it be able to adapt to?

Second: A list of **Constraints** -- limitations on the design. For example, are you limited to a certain amount or type of materials? Must it be within a certain size or weight? Must it be operable by one person?

> ***Educator's Note:*
> To help encourage originality later on, tell students they must include the constraint that their design cannot already exist, unless they make considerable changes.

Share the following example with students to help them understand these concepts, then offer assistance as needed in pulling relevant constraints/criteria for success from the research material. It may be challenging to distinguish whether a particular design requirement is a constraint or criteria for success.

This is OK, as the distinction is not important. The two categories are simply a strategy for approaching the design question from two different directions; the important thing is to capture these insights somewhere before moving on to brainstorming.

Sample Design Question: How might we create a device that encourages ATV riders to wear helmets?

CRITERIA FOR SUCCESS

- Incentivizes helmet wearing or prevents riding without a helmet
- Interchangeable between riders/helmets/ ATVs
- Must be subtle
- Durable
- Small and portable

CONSTRAINTS

- Cheap to manufacture (accessible to most ATV riders)
- Little to no effort to operate
- Needs to be battery or solar powered (if electric)
- Two pieces?

Activity: Brain Dump (15-20 minutes)

Objective:

Students conduct preliminary, mini brainstorming sessions on their design questions then use the outcomes of those sessions to assess which question(s) might be best to work on for the Showcase.

Materials:

- Giant sheets of paper or butcher roll
- Markers
- Sticky notes (small scraps of paper work in a pinch)

Procedure:

Bring the team (or teams) back together as a group. Before beginning the exercise, have a conversation with students about the concept of viability --in other words, how much sense it makes to try and solve a particular problem. Ask students what factors they might consider when assessing viability, in general and in the case of the IDX Challenge specifically. This might include things like: knowledge they have about the subject, the amount of time they have to work on the project and how much the problem really matters (i.e. how important is it, really, for astronauts to be able to eat fries in space?)

Model how the concept of viability might be used to give constructive feedback on an idea, e.g. "'Eating fries in space sounds fun, but I think it makes more sense to spend our time on something that helps astronauts stay healthy." This can be introduced as an alternative to simply declaring that an idea is "lame" or "no one cares."

The entire team(s) will now work on brainstorming ideas for each of the identified design questions they broke out to analyze in the first exercise. Teams should write each of their design questions at the top of a whiteboard or large piece of paper. Have students choose one of these questions to start with. Set a timer for three minutes and explain they will now have three minutes of silent, individual brainstorming. During this time, their goal is to come up with as many ideas as possible to address the question at hand, while meeting the identified criteria and constraints. They may express these ideas via words, drawings or a combination of both. Each idea should be written on its own sticky note and placed on the large paper/whiteboard.

When time is up, have students move directly onto the next Design Question and repeat the process again (and again, for any teams who have three DQs). Reassure students that they will have the chance to revisit and share their ideas in a few minutes.

Once brainstorming is finished, teams can discuss and share their ideas. Explain to students that **their goal is not to find a solution right now**, but rather to identify the design question, and set of possible solutions, that looks the most promising. (They are looking for the most viable questions and solutions, as discussed previously.) You may wish to introduce stickers or another system to help teams indicate ideas that make them excited, skeptical, that seem practical, etc. Encourage students to add any new ideas that come up to the paper.

By the end of the session, each team should have identified the design question they want to work on, along with a few top solutions they are interested in exploring further. This can be indicated by clustering these sticky notes in a particular area, circling, stickers, etc. Other ideas can be moved aside but should be retained somewhere in case they prove helpful later.

Session 6: Select and Prototype

At this point in the process, sessions will become much less structured as teams progress on their design ideas. Use the session overviews and objectives as benchmarks, while accepting that certain things may take more or less time depending on the nature of the design question, and the personalities of the team. Remember to continue whatever documentation practices you have in place.

Activity: Brain Walk & Selection (20-25 minutes)

Objective:
The team delves deeper into solution ideas and selects one to move forward into prototype.

Materials:
- Several large sheets of paper or whiteboard space
- Markers
- Timer

Procedure:
Students will begin today by refining their top solution ideas from the last session. Prior to the class, the educator should write each of the team's top solution ideas at the top of a large sheet of paper. Place each paper in its own space on a table or a wall. (If working with a large class, use regularly sized sheets of paper and have students pass them around the table instead.) Aim for at least two, but no more than four.

Have 1-2 students stand at each paper. Each student should have their own marker. Set a timer for 2-3 minutes. During this time, students should work on building out the idea on the paper before them. They can add details, new ideas, adjustments, questions or concerns. Students may talk with the other person at their paper, but conversation should stay focused on their solution area.

After time is up, call out "Switch!" and have students move on to the next solution idea. Students should read through the ideas proposed on the paper before them and then continue to build on them with their own thoughts. Continue this process until each student has visited each idea once.

Gather students back together. The team's task is now to select the most promising solution, based on previous constraints and criteria for success that have been identified. Provide students as much guidance and support as they need during this process as it is often the most challenging part. This is the idea the team will take forward into the Prototype Phase.

Activity: Prototype (30-40 minutes)

Objective:
Students create and compare low-fidelity prototypes of a favored solution idea and determine a basic design structure to model in 3D.

Materials:
- Pens/Pencils
- Scratch paper
- Laptops, tablets, or Chromebooks for research
- A variety of low-cost consumables and/or recyclables such as:
- Markers
- Yarn/string
- Duct tape
- Clothespins
- Rubber bands
- Pipe cleaners
- Packing foam
- Cardboard
- Scissors and box cutters
- Play-Doh
- Cardboard tubes
- Plastic containers and bottles
- Tin cans
- Miscellaneous scraps from around the classroom

Procedure:

Now that a solution has been selected, students may have differing ideas about what form this solution will take. The prototyping process will give them the opportunity to express their ideas physically and evaluate different design aspects.

Give students a pre-set amount of time (20-30 minutes, depending on time) and put up a timer they can see; this will help to keep them on task and keep you on schedule. Some students may wish to sketch their ideas first before starting to build; have pen and paper available for this. Make devices like laptops or tablets available and remind students they can use research to help inform their design decisions as they build. If possible, have students work on their prototypes in pairs, with students switching off between building and "project managing," i.e. conducting the necessary research and providing input on whether key constraints and criteria for success are being met.

At the end of the prototyping period, have students share their prototypes with one another and discuss how aspects of different prototypes respond to the design criteria and constraints. Encourage students to manipulate, modify or combine prototypes as they talk. As the discussion continues, have students make a list (or sketch) that captures elements the group agrees can be included in a 3D model of the item. Then make a list of design elements that still need to be decided or figured out. Continue discussing and refining the design until the end of the session.

During this conversation, it is the educator's job to maintain forward momentum. Ask guiding questions. If a seemingly helpful idea or question is steamrolled, reintroduce it into the conversation. If you have feedback about the design, express it gently but openly and ask students how they might find a workaround. If, toward the end of the session, the team has still not reached a consensus, do not force moving into the 3D modeling phase. Instead, encourage the team to take a step back. Provide an opportunity for 3-5 minutes of silent reflection and brainstorming on the problem at hand. Or allow students a few days to think and pick up the conversation at the next session. If you are sensing the current design idea is a dead end, consider having students brainstorm or prototype around an adjacent idea and see if it proves more fruitful.

If time allows, you are encouraged to spend 1-2 additional sessions brainstorming, researching and prototyping ideas before moving onto 3D modeling.

PART THREE: 3D MODELING AND PRINTING

Session 7: 3D Modeling

Objective:
Students begin work on a preliminary 3D model of their design idea in Tinkercad (or another modeling software).

Materials:
- Pencils
- Graph paper
- Design prototype(s) for reference
- Rulers
- Optional: Soft tape measure for measuring curved surfaces (cut string can also be used)
- Calculator
- Laptop computers for design and research work
- Additional (non 3D-printed) components that will be incorporated in design

Procedure:
Prior to starting 3D modeling, the team should reach a consensus on what the basic 3D structure will look like. If not, continue prototyping and brainstorming as outlined in Session 6.

At this point, there will be greater differentiation in team member roles. Guide the students in determining if it makes sense to develop their design in one piece, or if there are multiple components that can be designed by separate people. The group should also have a conversation about the dimensions of their design. Depending on the design idea, this may be informed by preexisting constraints (e.g. has to fit around one's wrist), compatibility with an existing object (e.g. built to fit a standard outlet), or simply in response to the look and feel of the prototype. Creating a reference sketch of the agreed upon design is a great idea.

The team should also consider the size constraints imposed by the equipment (5.5 cubic inches for the Flashforge). Is the team creating their 3D printed prototype to size or will it be a scale model? If so, what is the scale? Have students calculate all dimensions according to the scale and add it to the design sketch.

At this point, one or more students can begin work in Tinkercad. Students working in Tinkercad should generally have a design partner, who can offer feedback and direction based on what the group has decided and new discoveries that may happen over the course of the session. This collaboration is especially important in the early modeling phase. Encourage occasional switching off who is working on the design.

Students who are not working in Tinkercad can continue to brainstorm, prototype and research around unresolved design questions. New information should be shared with the design team. A student may also begin work on compiling documentation into a slidedeck.
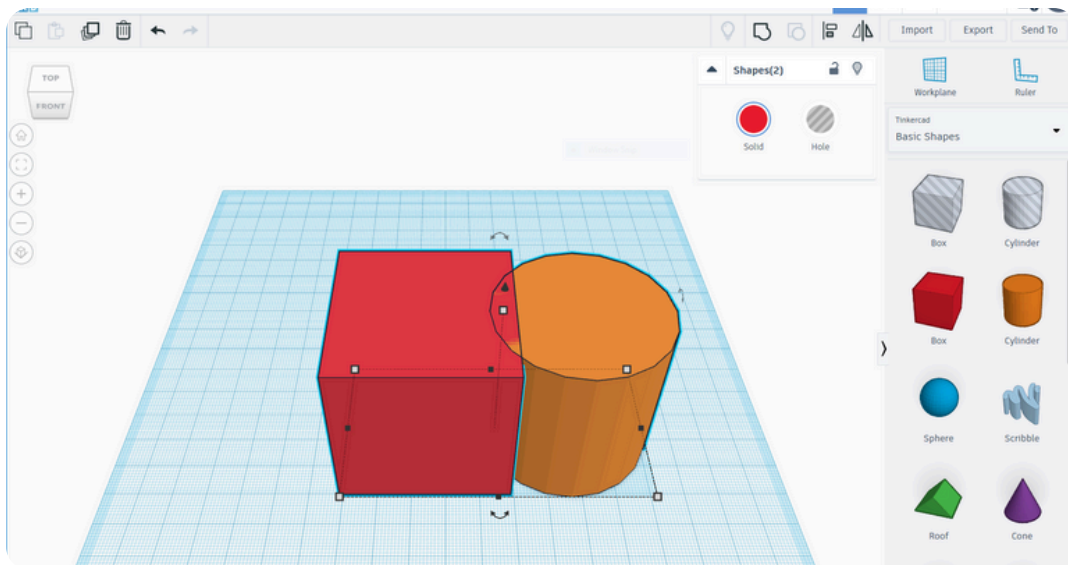
Session 8: Modeling & Test Prints

Objective:

Students complete an initial 3D prototype and prepare for test printing.

Materials:

- Pencils
- Graph paper
- Design prototype(s) for reference
- Rulers
- Optional: Soft tape measure for measuring curved surfaces (alternatively, cut string can be used)
- Calculator
- Laptop computers for design and research work
- Additional (non 3D-printed) components that will be incorporated in design
- 3D printer

Procedure:

Modeling and design work continues where it left off last time. Often by this point in the process, team members have settled into roles where they feel most comfortable. This is fine as long as students are communicating with one another and recognize the unique contributions of each person on the team.

Ideally, a test prototype should be printed prior to finalizing for the Showcase. When the model is ready to be printed, a student who was not the primary designer, with the educator's support, should inspect the design for consistency with the group vision, as well as any technical flaws (e.g. uneven edges, dimensional errors, not flush with the Workplane, etc.).

> ***Tip:*
> If the team's design has specific components that need to be test fit, such as a notch for an LED or two pieces that screw together, use the Cut Tool in Flashprint to only print the piece of the design that needs to be tested. Continue making small adjustments until the proper fit is achieved, then print the complete object.

Session 9: Modeling & Final Prints

Objective:

Students practice pitching their 3D printed prototype and incorporate feedback into a final version.

Materials:

- Pencils
- Graph paper
- Design prototype(s) for reference
- Rulers
- Optional: Soft tape measure for measuring curved surfaces (alternatively, cut string can be used)
- Calculator
- Laptop computers for design and research work
- Additional (non 3D-printed) components that will be incorporated in design
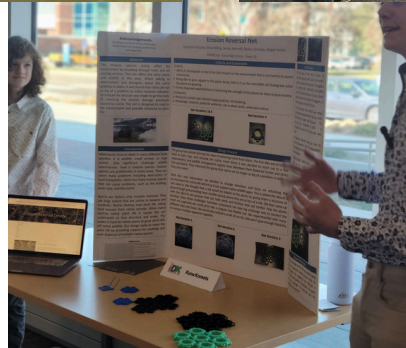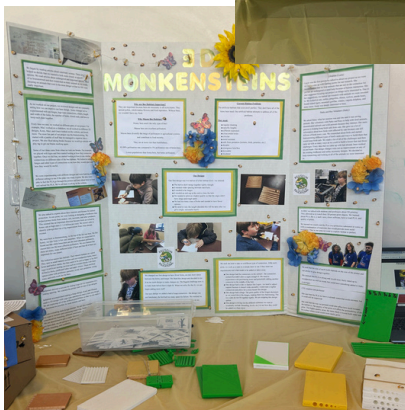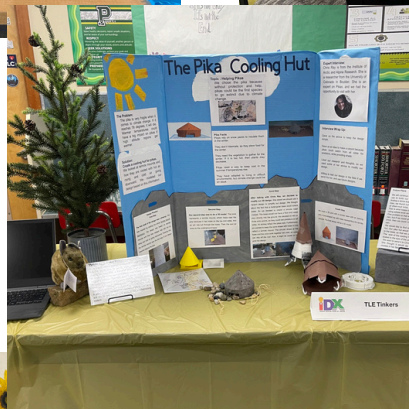- 3D printer

Procedure:

Following a successful test print, invite students to do a mock presentation of their prototype for you and a few colleagues, parents and/or mentors. This will serve the dual purpose of providing students feedback on their design idea & 3D printed model, while also giving them practice speaking about their design in front of an audience. After this "Feedback Session," the team should have their own conversation about adjustments they would like to make to their design. (If appropriate, have another Brain Dump where students brainstorm ideas about how to address problems raised during the session.) As the educator, guide students to make a realistic assessment of the issues they can fix between now and the Showcase. Anything they can't fix is something they can -- and should -- talk about during their final presentation!

Afterward, the team can work independently on making the agreed-upon design adjustments as well as finalizing elements for the IDX Showcase (slidedeck and presentation materials).

Session 10: Presentation Prep

If time allows, reserve the final session for planning the team's - 5-7 minute Showcase presentation, finalizing the slidedeck, and gathering artifacts for the Showcase table. A presentation board is not required, but many teams find it a helpful tool for organizing visual representations of the design process (sketches, prototypes, etc.) as well as creating a sense of team identity. Any final design adjustments, prints, gluing, assembly, etc. can also be completed at this time.

EXTRAS

3D Printing Workflow Activity Sheet

Enlarge and print the steps of the 3D printing workflow on separate sheets of paper, mix them up, and have students attempt to put them in the correct order as an inquiry-based introductory exercise to the 3D printing process! We suggest printing the phases and the results of each phase (written in all caps) on different colored or shaped papers and explaining the distinction to students ahead of time.

IDEA = something you'd like to create with the 3D printer!

      Modeling Phase → Create or obtain a digital model of the 3D object you'd like to print. 3D

MODEL = digital representation of a 3D object

      Exporting Phase → Export (save) your 3D model as an .STL file.

.STL FILE = Special type of file that represents the surface of a 3D object using tiny, tessellated shapes (usually triangles)

      Slicing Phase → Import your .STL file into a slicing software, where you can adjust specific print settings and convert it into a code the 3D printer can understand.

G-CODE FILE = Computer code file containing instructions for the 3D printer for how to print a specific object.

      Printing Phase → Prepare the printer for printing, then initiate the print.

3D OBJECT = A physical 3D object that has been manufactured with the 3D printer.

      Post-Processing Phase → Remove support material leftover from printing. Use different techniques, such as sanding and painting, to modify your printed object and get the final look you want.

      FINAL PRODUCT → The end result! Your idea brought to life.

Table Clip Design Brief (for beginners)

Brief:
Design a hook that clamps/clips onto the edge of your desk or worktable and holds the weight of a single purse, backpack or bag.

Step One:
Brainstorm and SKETCH your design on paper. Label relevant dimensions.

Step Two:
Use scrap cardboard, chipboard or folded newspaper and a little tape to make a basic prototype of your clip design. Check to see that it fits on the table and the angle of the hook makes sense. (This prototype is unlikely to be strong enough to actually hold weight.)

Step Three:
Model your design in Tinkercad.

Step Four (Optional):
Export your model as an .stl file and prepare for print in Flashprint. Print and test to see if it works!

Tips:
- Use the digital calipers included in your kit to measure the depth of the table you will be clipping to.
- Decide ahead of time the UNITS you will be using in your design (U.S. customary/inches or metric/millimeters). Conduct all your measurements in this unit, label your drawing accordingly, and make sure your grid is set to this unit in Tinkercad.
- If you're not sure how to make a hook, consider the different shapes available in the Tinkercad library of shapes and how you might be able to hack it.

Table Clip 2.0 Design Brief (Intermediate)

Brief:
Design a clip-on desk/table accessory for your partner. Interview your partner to find out the dimensions of their desk / worktable and what sort of desk accessory they might like to have. (Possibilities might be: a cup holder, pen organizer, headphones hook, place for their phone, etc.)

Step One:
Interview your partner for 3-5 minutes to get a better understanding of their design needs.

Step Two:
Brainstorm and SKETCH your design on paper. Label relevant dimensions.

Step Three:
Use scrap cardboard, chipboard or folded newspaper and a little tape to make a basic prototype of your clip design. Optional: Take a picture and message it to your partner.

Step Four:
Model your design in Tinkercad.

Step Five (Optional):
Export your model as an .stl file and email to your partner for them to print and test!

Tips:
- Don't start out your interview by asking someone what accessory they'd like to have. Instead have a conversation about how the person likes to use their desk, what their day looks like, any challenges they have run into while trying to keep things on their desk, etc. Problems to solve for may emerge over the course of this conversation
- Stick with designing an object that does one thing to keep the project achievable within the timeframe (and able to fit on the Flashforge bed)
- Remember that your design idea may require you to gather additional data/dimensions; for example, if you're designing a cup holder, you may have to get the dimensions of your partner's favorite mug or thermos.