Intro to Design and Discovering Your Design Challenge

Teacher Introduction and Lesson Plan

“The framing of a Design Challenge sets the stage for student teams to explore characters and problems within a situation. The best framing does not constrain them to one problem to solve nor leave it too broad that they have trouble finding tangible problems.”

- From An Educator’s Guide to Design Thinking by the d.school K12 Wiki

Introduction

Why Do Design?

Science is a rich discipline. It is overwhelmingly broad and deep—encompassing every aspect of our lives and spanning all other academic pursuits. History, math, art, literature, business, technology, athletics, psychology, medicine; science affects and is affected by all of them. Unfortunately, in the world of standardized tests we can become very focused on “getting through the content” and forget the applications of science outside of our classroom.

One of the most engaging ways to bring science content alive is to ask students to apply it in creative, innovative ways. Innovation is not usually a moment’s brilliance that changes the world. It is part of a process. In order to equip our science students as the innovators of tomorrow, we need to teach them the design process.

Engineering design is a blending of creativity and the application of science content. Now wait, I heard you just groan: “More stuff to teach!? Forget it!” Well, I would be lying if I said you wouldn’t have to explicitly describe the design process in order to use it in your classroom, but it doesn’t have to take up any more time than it would for you to describe the ground rules and expectations for any other project you would have done during that class time. This is more about how you teach science and less about adding to what you teach. The hope is that this series of lesson plans can be embedded in your curriculum with minimum effort. You can incorporate it with existing projects (like Science and Engineering Fair projects) with ease. It may be a little awkward at first as you and your students learn and practice it for the first time, but the rewards will be exquisite as science comes alive and students realize their creative potential. The content from their science book will mesh with the tentative ideas in their minds to become physical realities in their hands. Instead of delivering inert knowledge you will be equipping your students with active knowledge. They will be more knowledgeable, more confident, and more excited. And hopefully you’ll have fun as well.
The Design Process

The design process teaches creative problem solving: an important skill to hone for us as teachers and for our students as they move forward into the real world. One of the most important ideas surrounding the design process is that it is iterative. You may move back and forth between the steps in a nonlinear or repetitive manner as you work towards the best solution to your specific design challenge (and even as you define your design challenge). Stanford’s d.school K12 Wiki summarizes the general design process in five steps: Empathize, Define, Ideate, Prototype, and Test. These steps will be specialized for engineering design and expounded upon in the subsequent lesson plans.

Discovering the Design Challenge

Oftentimes this first step can feel like the hardest part of the design process. Students tend to cave under the frustration of “not knowing what to do” by Googling science fair projects. And on the opposite end of the spectrum, designers who have an idea enthusiastically skip the entire design process to implement their clever product or process. Taking the time to submit to the scaffolding provided here will accomplish two goals. First, it will keep students from skipping to the solution or will help them discover a problem in the case of a mental block. Second, it exposes students to an abbreviated version of the design process. Done efficiently, this activity can be completed in 5-10 minutes! It is also acceptable for you, the teacher, to develop the design challenges for your students or to create a single design challenge for the whole class.

Lesson Plan

Learning Objectives

- Students will be introduced to the engineering design process.
- The student, class, or teacher will develop a general direction for the design challenge.
- The students should have the opportunity to address multiple users, problems, or user needs associated with the design challenge.
- Students will learn that Georgia Tech is interested in recognizing high school innovators.

Materials Needed

- Innovation Challenge Introduction video (in development still)
- The Discover Your Design Challenge worksheet (attached) – 1 copy per student
- Vertical space for student brainstorming (if possible)- whiteboard, sticky notes
Important Vocabulary

Iterative – Having repetition. The steps of the design loop are iterative. You need to exercise flexibility to go back and forth between steps as you realize things you need to change or didn’t do right in previous steps. The design process is not a rigid structure.

Design Process – A specific set of steps used to develop, evaluate and refine solutions to problems or challenges.

Engineering- The process of creatively applying scientific principles and practical experience to design and build new or improved structures, machines, or processes.

Procedures

Teacher Prep

- Feel free to brainstorm a Design Challenge on your own and skip doing this step with your students. You can also do this activity as a whole class instead of having them work as individuals or in pairs.
- You might want to lead a discussion on the Design Process loop to the class with your projector after the Innovation Challenge Introduction video. Keep in mind that teaching the process will be embedded with applying the content from class to your project, so don’t feel like you have to explain the entire thing in detail.
- Make copies of the Discovering Your Design Challenge worksheet if students will be filling it out.
- As another approach, you can refer to the Design Challenge Creator 4.0 from the d.school website (refer to the Resources section of this lesson plan).

Frequently Asked Questions:

Why aren’t we immediately trying to be engineers and focusing on something technical like building a new kind of blender or making a better computer monitor?

Because first we need to know what the problem is and not assume we understand everything so that we can immediately jump to the solution. You might think that a new kind of blender is needed to make better smoothies. You could then spend loads of time and money reinventing the blender when actually what you needed to do to really resonate with your market was invent a way of selling fruit that was pre-blended. Your product flops and the pre-blended fruit industry starts making millions because they did their research. Students need to understand that there is a process to applying science as engineers.

What is a ‘character’? Why is that term being used on the student worksheet?

Characters will become what designers refer to as “users” or the “target population”. The general term of characters keeps us from assuming too much about their roles before we understand the setting.
**Student Activities**

*Engage:*

Tell your students that Georgia Tech is wanting to challenge high school students to be more innovative. Play the ~ 20 minute Innovation Challenge Introduction Video.

*Explore:*

Note: These instructions below are written assuming that students are working on the Discovering Your Design Challenge worksheet in the groups they will be in for the duration of their Innovation Challenge projects. Adapt it to the needs of your classroom.

1. Either break students into groups or let them choose their own. The optimal size is 3-5 students per group. If you are incorporating this project with the Intel Science and Engineering Fair (ISEF) then you should limit the group size to three students. Groups can collaborate to help one another during the design process for this case.

2. Hand out the Discovering Your Design Challenge worksheet and explain the instructions. Help students fill in the columns if they feel stuck. Step 1 is essentially a brainstorming session. According to d.school, the rules for brainstorming (that will be discussed in detail during the Ideate lesson) which apply to this setting are, defer judgment of all ideas, go for volume, stay on topic, one conversation at a time, build on the ideas of others, be visual, and encourage wild ideas.

3. As students begin to fill in the box at the bottom of the back page, move around and check their progress. Make sure they have tested their statements well against the questions on the page.

*Explain/Evaluate:*

Once all of the groups have finished, hold a class discussion where each group shares their statements. Provide a brief time after each group for feedback from teacher and peers. If time is limited, ask students to write their first impressions of each idea on an index card. Collect these and give them back to the groups to reflect on as they further develop their project.

**You’ll Know You’re ‘Done’ When…**

Each group has developed a general design statement that is neither too broad nor too narrow. This statement will be the guide for directing research and framing the actual problem later on.

**Suggested Connections to Specific Content Areas**

*These are ideas for Design Challenges in your specific content areas in case you are totally stumped:*

*General Science:*

  How can the laboratory experience be improved?

*Biology:*
What can be done to improve the process of detecting melanoma?

Chemistry:

How might we improve the heat-transfer process in our school?

Physics

How could you build a more cost-effective circuit for a device?

Other ideas can be found at [http://www.teachengineering.org/browse_subjectareas.php](http://www.teachengineering.org/browse_subjectareas.php)

Extensions/Enrichment

Invite students to watch the entire Inventure Competition from this year or previous years online through Georgia Public Broadcasting ([http://www.gpb.org/inventure_2012](http://www.gpb.org/inventure_2012)).

Additional Resources


Stanford’s d.school K12 Wiki: [https://dschool.stanford.edu/groups/k12/](https://dschool.stanford.edu/groups/k12/)

![Figure 2: The Design Process Re-visualized](http://dschool.stanford.edu/groups/k12)
Discovering Your Design Challenge

**Step 1: Plan Empathy**

**Fill in the space underneath each box below according these three guidelines:**

List some **settings** that interest you, places you interact with, or that relate to your course content (Ex: a store, a classroom, your bedroom, a local park, your job, the hallway, the gym).

List between three and six **characters** that interact in each setting you listed. Be specific and know that you are not restricted to human beings.

List at least four real or potential **problems** that you think might be an issue in this setting.

<table>
<thead>
<tr>
<th>Settings</th>
<th>Characters</th>
<th>Potential Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Example: the school computer lab</em></td>
<td><em>Computer security</em></td>
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<td></td>
<td><em>Uncomfortable chairs</em></td>
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<td><em>Abused equipment</em></td>
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<tr>
<td></td>
<td><em>Not enough resources</em></td>
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</tbody>
</table>
Step 2: Develop Define and Ideate

Choose one of your settings from the front and capture the situation in three different ways. The templates below are only meant as guides. If you get stuck, use a different setting.

Redesign the ______(situation)______ experience.

Design a way for _____(specific group of people)___ to better ____ (situation)____.

How might we help ____(achieve some goal)____?

Step 3: Prototype and Test

Time to test your statements to make sure they provide a rich and meaningful design challenge! The following questions are helpful in guiding your testing.

Question 1:
By working with your statement, do you think you will have the opportunity to address multiple characters, problems, and character needs? If not, make your statement more broad.

Question 2:
By working with your statement, do you think you will be able to find similarities between the characters, problems, and character needs? If not, make your statement narrower.

Write your final statement of the problem here!
Empathize

“Design thinking is a user-centered design process, and the empathy that comes from observing users enables design thinkers to uncover deep and meaningful needs (both overt & latent). Empathy, by definition, is the intellectual identification with or vicarious experiencing of the feelings, thoughts or attitudes of another. Three main techniques are used to gain empathy: interviewing, observation, immersion. The goal of the empathy mode is to discover gaps in between what people do and what people say they do. These gaps are the design opportunities.”

- From An Educator’s Guide to Design Thinking by the d.school K12 Wiki

Introduction

The scope of the design challenge might seem enormous at first (e.g., “improve the method of accessing textbook materials for students”; FYI this could turn into a fantastic engineering project! Will you design a new backpack, a new locker system, a new eBook, a new online platform to deliver information… don’t assume that if the statement from the previous lesson is too big that you’ve digressed from the curriculum or that it cannot be an engineering project). Empathizing allows you to walk in the shoes of the characters you identified in the previous phase and determine what their needs actually are.

To design successfully you need to design for a specific audience. The audience you design for is known as the target audience, customers or users. Their needs are what our design challenge should be trying to meet. They are the ones who will ultimately determine the success or failure of the final product. Therefore it is critical to understand exactly what their needs are so that they respond well to our final product and we are more successful. Our goal is to empathize with them. We’ll be acting on this through immersive observations and interviews. The data collected from the user interviews will be essential in defining the problem statement, so make sure to emphasize good note taking and documentation as your students begin interviewing their users. Defining the problem statement later on if students have a variety of documentations from their user interviews (this includes the perspective of a partner).

Understanding the users’ needs accomplishes half the necessary research. Good engineers need to be aware of how the existing products that are attempting to meet the needs of the customers work. Reverse engineering existing products helps students gain insight into what currently is being. Design is rarely the creation of something totally new and different. Usually, innovation involves elegant changes to existing products. Engineering does not mean reinventing the wheel.

Another way to inspire students (and help them get a sense of what designs are legally ‘off limits’) is to have them do a patent search. There are several websites that offer good patent search engines, especially www.google.com/patents/. Researching patent information is arguably more logical to do during the next phase, when the problem is defined. Doing the patent search too soon may narrow the scope of the project too soon and keep students from being able to explore all possibilities. It is up to the discretion of you as the teacher to determine when you want your students to do their patent search. I have included the details on using the Patent Search worksheet during this lesson plan, though.
Lesson 2 - Empathize

Learning Objectives

Collect data from user interviews, reverse engineering, and patent searches to fully understand the setting and collect the pieces that will frame the problem.

Materials

*User Interview worksheet*

*Reverse Engineering worksheet*

*Patent Search worksheet*

Important Vocabulary

*Patent* - An official document given by a state or government that allows exclusive right or privilege to an inventor for a specified period of time.

Procedures

Teacher Prep

Again, even though you might be doing a design challenge with the whole class, the lesson will be written as if students have picked design challenges as individuals or in groups.

You might want to spend the time to teach your students how to ask good questions in their interviews. This means 1) no questions with one word answers and 2) no leading questions. An example that commits both of these errors is, “Wouldn’t you like a glass of water?” This kind of statement projects expectations upon the user and leaves them no room to give an answer that might reveal underlying needs. For more on open-ended questioning including a lesson on how to implement it, go to [https://dschool.stanford.edu/groups/k12/wiki/63fcd/OpenEnded_Questions.html](https://dschool.stanford.edu/groups/k12/wiki/63fcd/OpenEnded_Questions.html). Another good tool for learning to ask good questions is How/Why Laddering, found here: [https://dschool.stanford.edu/groups/k12/wiki/afdc3/HowWhy_Laddering.html](https://dschool.stanford.edu/groups/k12/wiki/afdc3/HowWhy_Laddering.html).

There are ways that reverse engineering can be done in class by having students bring products to school to disassemble, but some students might not know the actual products they will seeking to improve or replace yet. Additionally, some students might be working on products that cannot be feasibly brought to school. It is up to you as the teacher to discern when and how to implement this. If the entire class is working on a single design project then it might make the most sense to make the reverse engineering an in-class assignment. Otherwise students will have to do this outside of class. I recommend asking students to keep a photo or video documentary when they reverse engineer any existing products.

**NOTE:** Because the focus of this project is supposed to be 1) engineering design and 2) curricular (although, if you are using ISEF for this project then the scope can be beyond the curriculum of your specific content area), you might have to exert some influence as a teacher to maneuver student projects in those directions at the end of this lesson.

Student Activities
1. Introduce the empathize phase of the design process by asking students, “What kind of research can you do before you develop a statement of your user’s needs?” As the facilitator of the discussion, make sure that (at least) the methods mentioned in the introduction are covered. To create even more buy-in from your students, ask them “Why are empathy and research important?”

2. Next, hand out the User Interviews worksheet. Students identified characters in their design settings in the initial design phase. Now they need to determine which of those characters they should interview. Encourage them to be specific in how they identify their users (e.g., “9th grade Hispanic girl who owns a computer similar to those in the lab” instead of “girl”). Even if students are doing individual projects they need to do the interviews in pairs. They will not be able to engage the interviewee and take notes simultaneously.

3. After students identify the users in their settings they need to choose questions to ask. Have them prepare good open-ended questions beforehand (these are discussed in the Teacher Prep section above).

4. If you are doing a design project where students are trying to meet each other’s needs then the interviews can be done in class. Otherwise they will need to do this part outside of class. If you are doing a class-wide design challenge and your school permits it you could even do a field trip to the setting where you would encounter users to interview.

5. After data from the user interviews has been collected, hand out the Reverse Engineering worksheet. For the sake of simplicity, I’ll assume all of the students have individualized projects and not all of them could bring their projects in to class to work on. Each sheet represents a single product that the student or group will reverse engineer, so if they plan on reverse engineering more than one product then they will need more than one sheet. After reviewing the questions on the sheet together and your expectations as their teacher, assign them to do the reverse engineering outside of class.

6. Last, have students do the Patent Search worksheet. Your students might have trouble coming up with key words, so if you ask them to do this outside of class then make sure you help them think of good words and phrases to guide their searches.

Assessments

The worksheets.

Suggested Connections to Specific Content Areas

General Science:

The interviewing process applies an important part of the scientific method: taking observations before drawing conclusions. The nature of science demands that scientists avoid bias during experimentation. It would be good to encourage your students to see their user interviews in the same light.
Lesson 2- Empathize

Biology
Chemistry
Physics

Extensions

From TeachEngineering.org:

*Relating to the Project - Role Reversal:* Have students imagine that they are members of the target population experiencing the problem and/or need outlined in the design challenge. From the point-of-view of a member of the target population, have each team develop three questions that they would ask the project engineers about the challenge. Share some of these as a class. If time permits, ask each student to write a short letter to a (hypothetical) engineer explaining how his or her life is impacted by the problem and/or need. How would his or her life, family and community be different if this need or problem were resolved?

Resources

TeachEngineering.org:

Stanford’s d.school K12 Wiki:
https://dschool.stanford.edu/groups/k12/
**User Interviews**

*Work with a partner* to conduct user interviews. This information helps you discover people’s expressed and latent needs so that you can meet them through your design solutions.

1. Which characters are your users? Identify *who* you plan on interviewing before you begin.
2. Gather raw data from your users using video, audio and/or notes. Get them to tell you their stories! Put yourself in their shoes. Avoid leading questions and questions with one word answers (if you need to, ask your teacher to explain this). Here are some possible questions:
   - Tell me about the last time you...
   - What was the best...
   - What was the worst...
   - And why is that?
   - Can you tell me more about that?
   - When do you use this product?
   - Why do you use this product?
   - What do you like about existing products?
   - What do you dislike about existing products?
   - What improvements would you make to the product?

3. Fill in a chart like the one below to document user feedback for each interview.

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<thead>
<tr>
<th>Question</th>
<th>User Statement</th>
<th>Your Insights/Interpretation</th>
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4. Look at your charts and make a note of any repeating comments. Group these comments together by using a descriptive word (Such as “feel” or “function”). These are indications of your customer *needs*. Express the needs in complete sentences.

5. Rank the needs in the chart below in order of importance for the user.

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<thead>
<tr>
<th>Rank</th>
<th>User Needs</th>
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<td>4</td>
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<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Step 2: Empathize — User Interview Worksheet  

Based on Resources from the d.school K12 Wiki and TeachEngineering.org

Specific User Being Interviewed (be descriptive!): ________________________________

<table>
<thead>
<tr>
<th>Question</th>
<th>User Statement</th>
<th>Your Insights/Interpretation</th>
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Reverse Engineering Worksheet

Work with a partner to reverse engineer an existing product. This means take an existing product apart to discover how it works and how all of the component parts interact to make the whole.

1. Describe the product that you will reverse engineer. Where is it typically used? Who might use it?

2. What is the primary function of this product? What customer need is it meeting?

3. What are the major components of this product?

4. List the detailed procedures you used to reverse engineer this product. On the back of this sheet, include sketches of the product and its parts (with labels). Take pictures or video during the process.

5. How do you feel this product could be improved? Is it effectively and efficiently meeting user needs?

Names_______________________________________

Date _________________________________________
# Patent Search

**Answer the following questions.**

1. What is your problem description? This should be stated as a design challenge.

2. What are some possible products that relate to the design challenge?

3. Give at least three examples of existing patents that relate to your design challenge.

**Suggested websites to use:**
- Google patent search: [http://www.google.com/patents](http://www.google.com/patents)

<table>
<thead>
<tr>
<th>Patent name:</th>
<th>Website:</th>
<th>Brief description:</th>
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How this relates to your design challenge:

<table>
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<th>Patent name:</th>
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<th>Brief description:</th>
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How this relates to your design challenge:
Define

“The Define mode is seen as a ‘narrowing’ part of the process. After collecting volumes of user information, it is time to distill down to one specific user group, their need and the insight behind that need so as to unify and inspire a team. The goal of this mode is to come up with at least one actionable problem statement... that focuses on the insights that you uncovered from real users.”

- From An Educator’s Guide to Design Thinking by the d.school K12 Wiki

Introduction-

What does it mean to ‘define’ an engineering design problem?

Now that you have background research it is time to boil it down to a well-framed and human-centered problem statement. First your team will synthesize all of the data from the user interviews, the reverse engineering, and the patent searches. Then, from that big picture your team will be able to narrow down a specific problem statement. Why? The problem statement gives everyone in the group a common focus. You know your solution will be grounded in needs that came from the customers and not from you.

The problem statement should do three things: identify the target population, their need, and why that need is important to them. Consider the following three items as you develop the statement:

1. **Specific users** – These could be people, animals or systems, but they should have been discussed in the empathize stage.
2. **Deep Needs** - What needs do your users have? Make sure you look at the data you gathered during the empathize stage to identify needs that are under the surface or unexpected. Use verbs! This is how you will define the problem that justifies the project.
3. **Insights** - Why do you think the user has these needs? Why is the need surprising or interesting? In this specific context, how does this need manifest? What is your interpretation of the observations?

The third aspect of the problem statement, why the need is important or insights, is what most designers forget. It adds significance to the project and will keep the solution focused on the user. Looking for similarities and patterns in your background research should help uncover insight.

Avoid using nouns in your problem statement. Instead of “Ajay needs a faster car” say “Ajay needs to get to work faster”. You limit the design possibilities when you use a noun in your problem statement. This can be tricky, so challenge your team to create a statement in the form of “User needs to [verb]” instead of  “User needs a [noun]”. The leading word (“a” versus “to”) switch should help your team focus on a problem without settling a single solution prematurely.

Project requirements and constraints will also begin to become evident during this phase. These are important vocabulary to be familiar with and their subtle difference can be confusing. The requirements of a project are more abstract than the project constraints. The primary requirement of a design project is to meet the user’s need. The constraints are the practical ways your design will be limited in order to meet that need. If your user needs (requires) a faster way to work, an obvious constraint might be that
they are restricted to ground travel. A more practical constraint might be that they cannot leave earlier than 6:00 am or later than 8:00 am.

It is very important that you distill down to only one need and a specific user. Solutions tend to get out of hand and become un-useable when there are too many users and needs being answered.

It will be hard to know if your problem statement is just right. This is where the iterative part of the design process will become apparent. If you move from ideating and into prototyping and just keep getting stuck, it might be time to go back to the define phase, look at your data again, and refocus the target audience or deep needs. So, for now, just go for it. Don’t split hairs or waste time arguing. Come up with a design statement and move on. You’ll know soon enough if it is right.

Lesson Plan

Learning Objectives

• Student teams will develop a problem statement for their engineering design project that identifies the target population, their need, and why that need is important to them.

Materials

• Defining the Problem worksheet

Vocabulary (from TeachEngineering.org)

Constraints – A restriction on the degree of freedom one has in providing a solution to problem or challenge.

Requirements – What a particular product or service should do. It is a statement that identifies a necessary attribute, capability, characteristic or quality. In engineering, sets of requirements are inputs into the design stages of product development.

Procedures

Teacher Prep

• This activity builds off of the Discovering Your Design Challenge and Empathize activities. They should be done with the students first.
• Make enough copies of the Defining the Problem worksheet (1 per student).
• Familiarize yourself with the different activities that your students can use to synthesize their data (one is specified below, the other in the Extensions section).
• Student groups should be the same as they were in the previous design phase.

Student Activities

Engage:

1. Have a picture of an iPhone on the screen as students walk in the door. Post the following warm-up question, “A large team of engineers created this as a solution to some problem that existed. What is one possible problem statement they could have been working from?”
2. Request volunteers to share their problem statements.
3. As students share, highlight the importance of specific users, deep needs, and insights.
4. Tell students they will now get a chance to define their own problem statement that could lead to a new device that no one has ever thought of.

**Explore:**

1. Break students into their project groups. If there are any individuals, have them work with the people that assisted them during the interview process.
2. Guide the students through an analysis of their empathize data.
   a. Stanford’s d.school K12 Wiki has a great methodology in the form of a lesson plan that helps students organize the data from user interviews into a problem statement. There are several different ways you can provide a framework for this activity. I do not recommend just handing them the worksheet and telling them to “figure it out”. I think that the best activity is the “Empathy Map”. It can be accessed here: [https://dschool.stanford.edu/groups/k12/wiki/3d994/Empathy_Map.html](https://dschool.stanford.edu/groups/k12/wiki/3d994/Empathy_Map.html)
   b. If the activity above does not seem like it would work with your students then I have listed a few alternate activities under the Extensions part of this lesson. Additionally, those activities might be good for students who are stuck or who feel uncertain about the problem statement they have formulated.

**Explain/Evaluate:**

1. After students have evaluated the data they received from the empathize step, team members should work together to complete the Defining the Problem worksheet.
2. Move between groups to facilitate discussion on their potential problem statements. As students begin to narrow it down, challenge them to explain how it addresses specific users, deep needs, and insights.

**You’ll Know You’re Done When...**

Students have a problem statement and are ready to begin brainstorming ideas that will address their design challenge.

**Suggested Connections to Specific Content Areas**

**General Science:**

This is not very different than how a scientist takes a large quantity of data and distills it into something manageable. Students are drawing conclusions (or, more accurately, inferences) based on data.

Developing a problem statement is just like developing a hypothesis in the scientific method. From here we will come up with ways of testing the hypothesis and implement them. If we are wrong, then we'll go back to whichever step needs to be revisited and try again. The scientific method is very similar to the design process.
**Biology**
This could be done as some kind of ecosystem exercise. EX: “Coyotes need to eat rabbits because they are an acceptable and easy form of energy”. There are dozens of other easy examples.

**Chemistry/Physics**
Inanimate objects don’t have “needs” in the same way living things do. You’ll have to indulge in personification to make these work, but that might make the abstract systems of physical science more appealing to some of your students. Give them a stack of data that leads to the conclusion “A single Oxygen atom needs two electrons because that results in greater stability” or “In order to change its motion, a box needs a force because it’s natural state is zero acceleration”. The steel ball on Newton’s cradle needs to transfer its momentum because energy must be conserved.

**Extensions**
Stanford’s d.school Wiki has additional activities you can do with your students to help them develop the problem statement. Because this phase can be tricky, it might be helpful to experiment with a few of these scaffolds and find the one that best fits your particular classroom. They are pleasantly presented in lesson-plan format.

2x2 Matrix – compares products on a two dimensional spectrum of traits and properties.
[https://dschool.stanford.edu/groups/k12/wiki/29e5a/2X2_Matrix.html](https://dschool.stanford.edu/groups/k12/wiki/29e5a/2X2_Matrix.html)

Journey Map – follows the history of an object, product, and customer.

Metaphor – an outside of the box way of describing your user’s needs.
[https://dschool.stanford.edu/groups/k12/wiki/4943e/POV_Metaphor.html](https://dschool.stanford.edu/groups/k12/wiki/4943e/POV_Metaphor.html)

**Resources**

TeachEngineering.org:

Stanford’s d.school K12 Wiki:
[https://dschool.stanford.edu/groups/k12/](https://dschool.stanford.edu/groups/k12/)
Defining the Problem

[Specific User] needs [Deep Need] because [Empathy-Based Insight].

Fill in the blanks by answering the questions below! Feel free to experiment with different combinations of users, needs and insights.

<table>
<thead>
<tr>
<th>Specific Users</th>
<th>Deep Needs</th>
<th>Empathy-Based Insights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe the target population — who specifically experiences this problem or need?</td>
<td>What needs do these users have? Look for the unexpected and don’t forget to use verbs (use “to” as your leading word instead of “a”)!</td>
<td>Why do you think the user has these needs? Why is the need surprising or interesting? In this specific context, how does this need manifest?</td>
</tr>
<tr>
<td>Describe the geographic area and population to be served.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Other Questions to Consider!

Overview of the Design Team
What are the team member’s qualifications to accomplish this project?

Overview of Proposed Project
What immediate and long-range results are expected? Will these results change people’s lives, the educational community and/or the world? How is this project unique? For example, is it similar to other projects but designed for a different target population? Does it employ a new approach?

Project Requirements and Constraints
What are the project requirements? What constraints have been placed on your team (money, time, size, etc)?

Project Activities and Timeline
What exactly must be done in order to achieve the desired outcomes? When, and in what order, must these activities be done to achieve the desired outcomes? Who will carry out project activities? Who is responsible?

Evaluation
By what criteria will the success or failure of this project be measured? What techniques or tools will be used to evaluate? Who will do the evaluation? When and how often will they do it? How will evaluation results be used? Who will see evaluations?

Funding
What is the anticipated total budget for this project? What are the anticipated sources of funding?

Step 3: Define Based on Resources from the d.school K12 Wiki and TeachEngineering.org
**Ideate**

“Ideation is the process of idea generation. Mentally it represents a process of “going broad” in terms of concepts and outcomes. Ideation provides the **fuel** for building prototypes and driving innovative solutions.”

- From *An Educator’s Guide to Design Thinking* by the d.school K12 Wiki, emphasis added

**Introduction**

*How do you brainstorm possible solutions?*

At this point you have done your research, defined the problem, and are ready to generate possible solutions! This is an exciting part of design. The Define phase narrowed our scope and the Ideate will flare back out based on the constraints from the previous phase. Typically, engineers and designers use the creative process of “brainstorming” to ideate. Keep in mind that your team should be more interested in exploring all possibilities than finding “that one perfect design” at this point. Don’t settle for the obvious solutions (don’t ignore them either). Build off of one another constructively to generate every possibility. There will be plenty of time for critical analysis later on, so ignore that instinct for now.

Even though brainstorming is very open ended and high energy, the rules defining how to brainstorm are some of the most important and rigid rules in the design process. I’ve adopted these from IDEO, the world’s leading design firm. There are several places they are available online, but the link to one of them, their online innovation platform OpenIDEO, is listed under the references of this lesson.
Brainstorming Rules!

1. Defer Judgement
   - Don’t be critical of any ideas at this stage, not even your own! Everything is fair game. Be intentional about creating instead of evaluating at this stage.

2. Go For Volume
   - Quantity is better than quality at this stage. Ideas can be refined later. For any given brainstorming session approximately 10% of the ideas will be clever, so the more ideas you have the more clever ideas you will have.

3. One Conversation at a Time
   - Brainstorming is a team activity because more heads are better than one. Therefore, make sure everyone is doing the same thing! As soon as the group starts thinking about multiple ideas at the same time, the creativity becomes fragmented.

4. Headline!
   - Be concise and specific! Wordiness is boring and keeps others from participating.

5. Be Visual
   - Don’t just talk – Write! Draw! Act! Express your ideas visually! Even if you are horrible at drawing, the idea behind a sketch is the most important. Feel free to build on the ideas of others by drawing someone else’s idea for them. Also, record everything.

6. Build on the Ideas of Others
   - Use and instead of but to follow up on someone else’s idea. Give momentum to their idea by adding your unique perspective. Encourage one another and be optimistic!

7. Stay on Topic
   - Explore ideas to the fullest but don’t get distracted and start moving beyond the scope of your design parameters. If you are trying to make a new way to scoop ice cream, don’t digress by discussing where the best place in town for gelato is.

8. Encourage Wild Ideas
   - Sometimes the wildest ideas turn into practical and brilliant creative leaps. Don’t limit ideas to what is feasible based on things like resources or technology. Dream big by saying, “What if...?” first. New technologies may come from trying to meet the needs of possibilities no one had been brave enough to voice before.

Teacher Tips for Brainstorming:

The space your students brainstorm in is important. This includes allowing mobility, having music, standing and sitting options, having room and resources to write and draw, and fostering an environment that students find safe for self-expression. Give students flexibility and freedom of expression but have an iron grip on fair play and respect. Think about designating group leaders within each brainstorming team. The aforementioned rules provide a good framework for guidelines by which everyone can get along. Encourage students to explore their brainstorming prompts thoroughly but to move on when the energy falters. Brainstorming prompts usually look like the phrase “How might we _____?” Guidelines for creating these with your students are discussed in the Student Activities section below.
Lesson Plan

Learning Objectives

• Teams will create a large pool of ideas that meet the various customer needs and design challenges set before them.

Materials

• *Brainstorming Rules* - have the document available as a worksheet for each team, projected somewhere visible, or printed as a poster so that students can use it as a reference.
• Large pieces of paper or large whiteboard spaces
• Markers
• A lot of sticky notes – minimum of two colors
• Copies of the *Brainstorming worksheet* (1 per individual or team)

Important Vocabulary

*Brainstorm* - A creative team activity intended to generate a large number of potential solutions to a design challenge

Procedures

*Teacher Prep*

• Make sure students have defined their problem (user, need, insight) as described in the previous lesson.
• Students will be working in the same groups they have been in since the first lesson. In case you were wondering – yes, these groups will continue to the end. It is ok to combine groups and allow them to brainstorm together on each other’s ideas. Just because it isn’t “their” project doesn’t mean they can’t assist. This lesson works best in the classroom, so combining groups is easier to facilitate on this lesson than most others. Make sure groups divide the brainstorming time in half to ideate equally on one another’s projects.
• Create some way for the brainstorming rules to be visible to the entire class throughout the lesson. They can be projected from your computer, you could print them on a poster, or you can use an overhead transparency – just make sure they are visible and easily referenced.
• Have several large sheets of paper or large whiteboards per team. Gather various colored writing utensils and something for hanging up the papers/whiteboards during and after brainstorming.

*Student Activities*

*Engage (optional - if students are already invested in their projects and excited to move forward):*

1. Do a practice brainstorm as a class. Suggestions are included under the *Extensions* section.
**Explore:**

1. Before students can begin brainstorming they need to develop **brainstorm prompts**. These will provide the spark, focus and direction that will fuel the creativity of the brainstorm. Stanford’s d.school recommends that these prompts be in the form of “How Might We ______?” statements. For example, the user might say, “I am a college student and I hate folding laundry because I can’t seem to fold it the right way.” Our brainstorm prompt would be phrased as, “How might we create a tool to help the college student fold laundry?” Help students turn their problem statements into a few (more than one or two) brainstorm prompts before they begin (“how might we” can be abbreviated “HMW” since you might be writing it several times).

Reference the list of needs that students should have from the empathy (or define) worksheet where user needs were identified and ranked. This will help develop HMW statements.

2. Review the brainstorming rules as a class. I suggest that you go through each rule *without* providing the explanations I’ve written and have students try and explain 1) what each rule means and 2) why it is important. This will create better buy-in. After they’ve done that for the list, then read the explanations to reinforce the class discussion.

3. Give each team a big piece of paper and a few markers.

4. Ask teams to write their first brainstorm prompt at the top of their paper.

5. Go! Tell students to start covering their writing space with drawings and ideas that address the HMW statement at the top of their paper. As soon as ideas begin to dry up, switch to the next HMW statement. Give the teams anywhere from 15 to 30 minutes.

   - **Tips in case a team gets stuck**
     - Brainstorm opposites.
     - Tell teams to create extreme constraints and see what they come up with.
     - For example, “must be as big as a school bus” or “must be small enough to fit in a locker” or “must cost more than $1 million” or “can only cost $5”.
     - Rearrange or relocate a team’s brainstorming space.
     - Try combining two seemingly unrelated ideas
     - Sometimes students stop brainstorming because they fixate on a single idea that they are attracted to. Encourage them to go for quantity...

**Evaluate:**

1. At the end of the time limit, have teams look for patterns and categories among their ideas. Ask them to circle, connect, or otherwise label the ideas so that they can see recurring themes. Not all ideas will fit in a category, but that doesn’t mean that they were “bad ideas”. Make sure ideas are clearly grouped under their associated HMW statements.

2. As teams finish categorizing their ideas, have them fill in the top half of the **Brainstorming Worksheet**. You can choose to have them do this as individuals or as a team, there are pros and cons to either method, so you should choose what is best for your setting.

3. Hang or otherwise place the writing spaces from each group around the room so that teams can walk around and look at each other’s ideas.
4. Pass out the sticky notes. Students should have several sticky notes in two different colors.
5. Indicate that one color sticky means "ideas I like," and the other color "questions" or "suggestions for improvement."
6. Begin a gallery walk where teams move about the room and look at the brainstorming sessions other groups did. When they see an idea they like, have them write an encouraging note on the appropriately colored sticky and put it next to the idea. When they want to build on an idea or provide critical feedback, have them write the remark on the other colored sticky note and place it next to the accompanying idea.
   - I like to structure this activity such that students have 1-2 minutes at each group’s writing space and rotate as a team according to a timer or watch. If this isn’t your style, modify it or allow a free-for-all. However, make sure that each group received good feedback by the end of the session.

**Explain:**

1. Have groups return to where they brainstormed and review the sticky notes. Allow them to talk about the feedback from their peers amongst themselves for a few minutes. At the end of this time, have them fill out the two questions at the bottom of the Brainstorming Worksheet.
2. Have students save their brainstorming space for future reference. If they used whiteboards or you don’t have space, take pictures.

**You’ll Know You’re Done When...**

Each team has a substantial number of ideas and is ready to spend time assessing them to determine where to start prototyping.

**Suggested Connections to Specific Content Areas** - These will be developed as part of the pilot during the 2012-2013 school year.

- General Science:
  - Biology
  - Chemistry
  - Physics

**Extensions**

- If you want to warm up the class with some brainstorming practice, here are some suggested questions to ask the class. Make sure you actively practice the brainstorming rules with your class.
  
  **NOTE:** Words like “better”, “nicer”, “more efficient”, or “more attractive” are vague. Spend time discussion the importance of the group agreeing on the different facets of these vague descriptors.
  
  - How might we design a more user friendly student desk?
- How might we design a better experience for getting tickets to school events?
- How might we create a security system for the classroom?
- How might we discourage bullying at the school?

This is a fun activity to engage students before they begin brainstorming. IDEO is the world’s leading engineering design and innovation consulting firm (http://www.ideo.com/). NBC did an 8 minute spot on IDEO’s innovation process by challenging them to redesign a shopping cart. You can watch it at http://www.youtube.com/watch?v=M66ZU2PclCM. Have students identify components of Empathize, Define, Ideate, and even Prototype (even though they have not done that lesson yet). You could initiate a class discussion about the importance of testing a prototype and what step in the design loop different problems in a shopping cart prototype might send you back to.

- If you want to try other structured brainstorming activities, check out the d.school’s K12 Wiki. The two I recommend are Bodystorming (https://dschool.stanford.edu/groups/k12/wiki/48c54/Bodystorming.html) and Crowd Sourcing (https://dschool.stanford.edu/groups/k12/wiki/81fa0/Crowdsourcing.html).

Resources

TeachEngineering.org:

Stanford’s d.school K12 Wiki:
https://dschool.stanford.edu/groups/k12/

OpenIDEO’s Rules of Brainstorming
http://www.openideo.com/fieldnotes/openideo-team-notes/seven-tips-on-better-brainstorming/
Brainstorming Rules!

1. Defer Judgment
   Don’t be critical of any ideas at this stage, not even your own! Everything is fair game. Be intentional about creating instead of evaluating at this stage.

2. Go for Volume
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Brainstorming

Once you have finished brainstorming, identify the following ideas on your space:

- **The Pet Project**
  - Which idea is your personal favorite?

- **The Sure Shot**
  - Which idea is most likely to succeed?

- **The Big Breakthrough**
  - Which idea seems out of reach but would be amazing if it actually happened?

Describe the above ideas more than they were on your writing space.

After the gallery walk, look at the sticky notes on your writing space and respond to the questions below.

1. Where are most of the "ideas I like" sticky notes concentrated on your brainstorming poster? The ideas and concepts that other students liked are…

2. Where are most of the "questions or suggestions for improvement" sticky notes concentrated? The ideas and concepts that need further development are…

Step 4: Ideate  
Based on Resources from the d.school K12 Wiki and TeachEngineering.org
Analyze and Prototype

“Engineering analysis distinguishes true engineering design from tinkering... [it] is the internal guidance of the project.”

- From TeachEngineering.org

“Prototyping is the iterative development of artifacts – digital, physical, or experiential – intended to elicit qualitative or quantitative feedback. The act of prototyping implies “building”, testing, and iterating and is itself, both a flaring and a narrowing process. The flaring represents the proliferation of low-resolution prototypes developed as different aspects of the prototype are evaluated. The narrowing represents the... [analysis] of the lower resolution models into increasingly complex and resolved models based on feedback that leads to an even better understanding of the user’s needs.”

- From An Educator’s Guide to Design Thinking by the d.school K12 Wiki

Introduction

How do you prototype a design?

Engineering analysis is what separates engineering from tinkering or art. How do you decide which of the designs your team brainstormed is best? How will the different parts of your ideas interact? How do you define “better”, “more efficient”, or “more attractive” when comparing designs? Engineering analysis provides an analytical approach to quantitatively determining the best design. It forces the designer to consider the important attributes that their design must or might have. Sometimes the design that turns out to be the “best” is unexpected! Trust the evaluation matrix and start with that design instead of the one that your instincts have a greater affection towards.

After a design has been chosen, it needs to be built. One of IDEO’s mantras is “Build to think”. Sitting around and thinking about what the design should look like or do can only get you so far. Eventually you have to pick up some materials and create something with your hands. In a team this is especially important. Your ideas are communicated much better when they become tangible. To demonstrate how a product might look or function, designers build a model or “mock-up”. They help the designer (and sometimes the user) better articulate what they want and/or need.

Mock-ups can be thrown together with simple materials (see the suggested list below) that serve to give a general impression of the eventual functionality or appearance. A mock-up can be used to highlight a specific feature or criterion of the design. For example, if you are designing a new type of personal camera, you might build a mock-up that is only used to communicate the ergonomics of the camera case that does not work and a different mock-up to demonstrate the technology inside of the camera while ignoring size or attractiveness.

If mock-ups are the outline of the final product, prototypes are the rough draft. The prototype needs to be a close approximation of the final product even if it is still “rough around the edges”. They are the unrefined versions of the final product that engineers build prior to large-sale manufacturing in order to test performance, design options, safety, and other specific unknowns. Prototypes create an authentic experience that allows for immediate feedback from either you as a designer or the customer as a user.
The prototype of a new personal camera might have a hard plastic shell that will be tested for durability by dropping the prototype on a hard surface. To test how the different features interact, the technology of the camera would be assembled within the plastic casing. The final prototype might be unrefined, but it allows the designer to quantifiably test some of the criteria they identified during analysis. It is important to understand what specific design variables your prototype is allowing you to explore.

Prototypes also teach students the reality of working with materials. For example, the students might have planned steel casing but might discover cost or weight constraints that force them to use plastic. Or, they might have planned on using wood but realized that it was difficult to form and gave their user splinters and so switched to plastic. The learning experience of trying to build something is priceless.

Check with your school to see what machining and manufacturing equipment is you already have. Alternatively, contact people in your community who have access to these resources. Local universities, community colleges or technical schools usually have manufacturing resources and you may be able to arrange for students to use them. Also, smaller engineering or manufacturing companies might be willing to help students with simple manufacturing.

The most essential skill of prototyping successfully lies beyond manufacturing. The key to letting your prototype morph into a successful final product is the ability to “let go”. This means that you can’t get too emotionally wrapped up in making this one idea work. You need to let it evolve and respond to the needs of the customer and the data from testing. Obviously, this will be a bigger part of the next design phase (testing) but it is important to mention now so that students can begin to craft their expectations appropriately.

Mock-ups can also be an important part of the ideation process. A team might find it easier to communicate and build on one another’s designs if they have a kit if simple materials to model their ideas with. Also, the whole design process is cyclical and iterative. A team might have a mini-brainstorming session while building some component of their prototype where they throw rough models of the final product together. If a specific component needs to be brainstormed in the middle of the prototyping phase, encourage the teams to follow the protocol of brainstorming.
Lesson Plan

Learning Objectives

• Students will identify the most important criteria of their design and the best design from their brainstorming phase to start prototyping.
• Students will create a representation of their final design that allows them to evaluate specific features and eventually develop several iterations.

Materials

• Evaluating the Ideas Worksheet
• Graph paper and rulers for each student

Suggested materials for mock-ups:

Blue masking tape                      Metal coat hangers
Scissors or craft knives                (unwind them and let students use the thick
Popsicle sticks                         wire as a flexible structure)
String                                  Poster board
Pipe cleaners                           Post-it notes

Important Vocabulary

Mock-up – a model of the final product that communicates the appearance or functionality of some or all of the final product.

Prototype – an unrefined version of the final product that is used for testing. Prototypes help designers learn about the manufacturing process of a product, how people might use it, and its durability.

Criterion – an aspect or component of the final product that has value to the user, designer, manufacturer, or distributor.

Engineering Drawings – A way to accurately and unambiguously capture all the geometric features of a design to allow another person (such as a machinist) to produce that component or product.

Manufacturing – The use of machines, tools and labor to make things for use or sale. On a large scale, the transformation of raw materials into finished goods.
Procedures

**Teacher Prep**

- Make copies of the *Evaluating the Ideas* Worksheet for each group. Review the worksheet so that you are familiar with its goals and expectations.
- Collect various materials and tools that students can use to construct prototypes.
- Students should continue in the same teams that they have been in since the first lesson of this unit. It does not make sense to combine groups for this step as you might have done for previous lessons in this unit.

**Student Activities**

1. Hand out the *Evaluating the Ideas* worksheet and go over the rubric and activities with your students. Explain the importance of engineering analysis.
2. Have teams make their list of criteria, assess their relative importance, normalize and rank them, and then use them to evaluate the different design options they developed during the ideation phase. The design with the highest value is the “best” design. 
   
   *NOTE:* this might be a logical break in your lesson if you need to space this lesson over more than once day. Feel free to stop here and pick up with prototyping another day.
3. Explain to students the difference between a prototype and a mock-up. Ask them to come up with reasons for building prototypes and why companies may or may not share their prototypes with the general public.
4. Show the materials available for mock-ups and discuss any safety concerns (especially if you are using hot glue or craft knives).
5. Give students time to experiment with the materials and then begin building mock-ups of their product. I suggest the students be given 20-30 minutes of build time. At the end of this time, stop the class so that teams can share their progress. Have each group show the class their model, explain its purpose, and describe any challenges they have encountered. Facilitate a class discussion to brainstorm solutions.
6. Now that students have made their design choice a more tangible reality, have them draw formal sketches of their final product. Hand out the graph paper and rulers and ask students to draw their product from several different perspectives (above, below, from the side etc). Make sure they include dimensions in their drawings and try to draw their sketches to scale. A good way to do this is to choose an appropriate equivalent dimension for the length of the side of a single square on the graph paper. Make sure that students choose a length that uses the space on the paper well without running off of the paper. 

   **SAFETY FIRST!**

   For the first time in the design process, safety issues are very important during this step (and the next step). Some of the construction techniques used in prototyping especially can be very dangerous. Review safety procedures for every piece of equipment used, and if possible, have adult supervision as often as possible. Outside of class, you might want to solicit parental support towards this end.
dimension of the final product equivalent to the short length of the piece of graph paper.

*NOTE:* If you have the time and resources, consider using CAD to extend this part of the process. See the Extensions section below for more detail.

7. The actual prototypes should probably be built outside of class time. If your school has a manufacturing space (also known as a Hackerspace or Makerspace) then the students could build their prototypes there. Prototypes do not need to be complicated. Most resources for building the prototype should be available at your school or at the student’s home. If a student or group is limited by resources they think they need, encourage them to look for alternatives online. There is a large, creative online presence in how to do clever and complicated things with cheap and simple resources (the do-it-yourself or DIY community).

**You’ll Know You’re Done When...**

Students have determined the best design to pursue first, have built several mock-ups of the different components and criteria, have built their first prototype, and are ready to test it.

**Suggested Connections to Specific Content Areas**- These will be developed further during the 2012-2013 school year as part of the pilot program.

General Science

Biology

Chemistry

*Physics* – The applications are endless! Forces and free body diagrams should be an easily integral part of the prototyping phase. Have students do FBD’s from their sketches. If their prototype involves circuits, have them do some simple circuit analysis. Is there motion? Kinematics, conservation of energy, and the impulse momentum theorem should all be applicable. Material science is not a standard part of most physics curriculum, but it might be helpful to introduce the ideas of stress and strain and the stress strain curve for the materials your students will be using in their prototypes. Hooke’s Law is an easy approximation for the forces a material will resist with. It can be applied to button pushing, handle squeezing, and trigger pulling activities (how much force is a user comfortable exerting to complete a task?).

**Extensions**

- Have your students design their prototype and it’s components on the *computer* before they build it! Computer aided design (CAD) is an essential skill for any engineer. There are a variety of CAD software platforms out there, but unless your school already has a license it is an expensive investment. Fortunately, there are also several open source (free) 3D modeling platforms that you and your students can learn the basics of computer modeling such as Google SketchUp, Archimedes, DraftSight, FreeCAD, and Creo Elements. If your school has access to a rapid prototyping machine, 3D drawings on the computer can become physical realities. There are several high-end expensive options for 3D printers, but there are also rapid prototyping
machines that cost significantly less (although the final product will generally be a little more rough). Check out the UltiMaker and the MakerBot as two less expensive examples.

- Great lesson for understanding mock-ups: https://dschool.stanford.edu/groups/k12/wiki/e7aa3/Looks_likeWorks_like.html
- Learning how to isolate a specific criterion for testing: https://dschool.stanford.edu/groups/k12/wiki/d0a91/Identify_a_Variable.html

Further Reading for your Personal Professional Development!

http://www.innovationtools.com/Articles/EnterpriseDetails.asp?a=158

Resources


Stanford’s d.school K12 Wiki: https://dschool.stanford.edu/groups/k12/
Some Types of Engineering Drawings

- Hand-drawn engineering drawing of a bench
- Exploded view drawing of bathroom exhaust fan
- CAD drawings
- Blueprint of building design
Evaluating the Ideas

You brainstormed a lot of ideas, but which one is the best? How do you know? How can you quantifiably compare the different parts your ideas share? Use the following steps to decide which design your group should prototype first.

Step 1: Identify Criteria

What are some of the important criteria that will define your product? Some possibilities are size, weight, appearance, time to produce, cost to produce, availability of materials, environmental impact, safety, ease of use, or market size. The user needs you identified during the Empathize Phase should direct the identification of these criteria. Make a list of eight criteria (picked from the list above or developed by you and your group) below:

1. 
2. 
3. 
4. 
5. 
6. 
7. 
8. 

Step 2: Assign Priorities Values to Criteria

a) Which criteria is the most important? Safety? Cost? The Evaluation Matrix helps engineers objectively determine a ranking for their criteria. On the back of this sheet, write the eight criteria both in the rows down the left and columns across the top of the Evaluation Matrix.

b) Poll the team for their opinions of the relative importance of one criterion over another. For example, the first blank cell on the top left (not the grey one) tallies the number of people who feel that Criterion 1 is more important than Criterion 2. Let’s say you have five people in your team, and three people feel that Criterion 1 is more important than Criterion 2. Then you would write the number 3 in this first blank cell on the top left. You would then write a 2 in the off-diagonal cell—the one that ranks Criterion 2 against Criterion 1 (if this seems confusing, think about saying to yourself “Criterion [# in column of criteria] is more important than Criterion [# in row of criteria]”).
c) Add the number across the rows for each criterion and write this number in the **ROW TOTAL** cell.

d) Add the **ROW TOTAL** numbers down the column to find the **COLUMN TOTAL**.

### Step 3: Normalize the Priority Values

To get a better feel for the relative priority values, you can normalize the values, which mean to calculate each value as a proportion of a total that equals 1. To normalize the priority values, divide each **ROW TOTAL** by the **COLUMN TOTAL** and write this number in the corresponding **NORMALIZED VALUE** cell.

### Evaluation Matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Criterion 1</th>
<th>Criterion 2</th>
<th>Criterion 3</th>
<th>Criterion 4</th>
<th>Criterion 5</th>
<th>Criterion 6</th>
<th>Criterion 7</th>
<th>Criterion 8</th>
<th><strong>ROW TOTAL</strong></th>
<th><strong>NORMALIZED VALUE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
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<td>Criterion 4</td>
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</tbody>
</table>

| **COLUMN TOTAL** |             |             |             |             |             |             |             |             |               |                     |
Step 4: Compare Alternative Designs

a) Order the normalized criteria values from largest to smallest. You have objectively determined the most important criteria and put it at the top of the list! The least important is at the bottom.

b) Write each criterion and its corresponding normalized criteria value in the Decision Matrix (page 4). Pick five designs your group brainstormed during the ideate phase and write them along the top row.

c) Now, rank each design concept according to how well the group feels that concept could satisfy each of the design criteria identified. Use a consistent scale (for example 0 – 5). A ranking of 0 means that the team feels the design concepts does not meet the criterion at all. A 5 means that the team feels the design concepts meets the criterion perfectly. Write these ranked values in the gray cells below each design.

e) Multiply each ranked value by the normalized priority value and write this number to the right of the ranked value for each design (in the white cells).

f) Sum these multiplied values and write them in the corresponding TOTALS cell.

Step Five: Analyze Results

a) The design with the highest value (as shown in the TOTALS row) is the option that best meets the selected criteria. Now you can quantitatively justify which design is actually the best! Designs with significantly lower total values can be discarded. The design with the highest score may be selected, or you can select the option that received the highest score for the majority of the categories.

b) Which is the design with the highest value?

c) Which idea will you proceed to prototype?
# Decision Matrix

<table>
<thead>
<tr>
<th>Criteria (ranked by normalized criteria value)</th>
<th>Normalized Priority Value</th>
<th>Design #1</th>
<th>Design #2</th>
<th>Design #3</th>
<th>Design #4</th>
<th>Design #5</th>
</tr>
</thead>
</table>

**Totals** 1.0

*Rank the designs according to their total scores (greatest to least) below:*

1.

2.

3.

4.

5.
Test

“The test mode is another iterative mode in which we place our low-resolution artifacts in the appropriate context of the user’s life. In regards to a team’s solution, we should always prototype as if we know we’re right, but test as if we know we’re wrong—testing is the chance to refine our solutions and make them better.”

- From An Educator’s Guide to Design Thinking by the d.school K12 Wiki (emphasis added)

Introduction

How do you know if your prototype works?

How well did your evaluation matrix reveal the best design? How will you know what works about your design and what does not? During the Empathy phase we stressed a human centered attitude towards design. So, once the prototype has been built, it needs to be delivered into the hands of the user for immediate feedback. Does it meet the needs that you thought needed to be addressed? What additional and previously unconsidered concerns reveal themselves from testing and feedback?

During the previous phase, you were building in order to test. The purpose of testing is to hone in on the correct solution. Testing gathers data on potential solutions. That data is the tool used to iterate the prototype into a new and better version of the design. Testing requires flexibility and insight.

Obviously, it is important to create authentic experiences during the testing phase. If you need to design a chair that can support 400lb, you can’t put 350lb on the chair and assume you’ve done a good job. Similarly, if you are to design a better hair dryer, you need to actually put your prototype in the hands of users and have them test your product when and where they would dry their hair in order to get authentic feedback. You need to look at how you defined “better” (according to the ranked criteria you developed on the Evaluating the Ideas worksheet) and measure those things as quantitatively as possible. If your new hair dryer is supposed to leave hair less brittle, then you need to use a device to measure the brittleness of hair dried using a standard dryer and hair dried using your new product and then compare the two to show a significant difference.

This is where the true iterative part of the design process becomes truly evident (see Fig. 1).
Feedback and data from either a user or tool of measurement need to be synthesized (Empathy and Define). The needed change is identified and solutions are offered (Define and Ideate). Solutions are implemented and a new round of feedback is sought after (Prototype and Test and back to Empathy).

Lesson Plan

Learning Objectives

- Students will create testing scenarios that examine specific features on their prototypes, will solicit feedback, and organize results to inform future iterations.

Materials

- Feedback Quadrants worksheet
- Testing Feedback worksheet
- Paper rubric for Engineering Design Project
- Students should bring their prototypes to class

Important Vocabulary

Iteration – Repeating a series of steps to get closer to a desired outcome (that is, re-design, re-test, re-build to get closer to an optimal engineering solution to a specific problem); can also refer to a version of the final product or solution.

Procedures

Teacher Prep

1. Make copies of the Feedback Quadrants worksheet so that each group has a sheet for each group in the class. At the end of the exercise, each team will receive a filled in quadrant from every other team.
2. Copy the Testing Feedback worksheet (1 per group)
3. Copy the Engineering Design Project Paper Rubric (1 per student)
4. Before the lesson: Instruct students to bring prototypes to class and have a 1-2 minute presentation where they create an experience for a user (their classmates) with their device.

Student Activities

Engage

1. Break students into their groups. They should all have brought their prototypes to class. Then, pair off each team with another team so that they can present the designs to and test the designs on one another.

Explore

2. Hand out copies of the Feedback Quadrants worksheets. Give each individual a worksheet. The quadrants are a means of organizing student feedback. The upper left stands for “what did the user like?”, the upper right is for “dislike”, the bottom left is “what new questions do we have?”, and the bottom right is for “what new ideas do we have?”.
3. Ask the teams to present their products to the team they are partnered with. They need keep their presentation under 2 minutes (1 minute is preferable) but must explain the problem or need that the product is designed to solve, talk about the target audience, and show how the product works and what it does. The time restriction demands that the students carefully consider and develop an economy of words. When they have finished, the presenting team needs to create an experience for the other team where they can use or engage in their design in order to give feedback. After the presenting team has handed over their design to be experienced by the other team, they should allow exploration and feedback from the exploring team without justifications or explanations. They gave their pitch – now they need to observe customer interaction and record what is said and done. I suggest 1-2 minutes where only the team doing the experience can talk. Encourage them to give feedback specific to the four quadrants. During and after this time, the silent team should be filling out their Feedback Quadrants worksheet.

4. Once teams have finished, have them swap roles.

5. If time permits, repeat the activity by pairing the teams differently. This will give each team more diverse feedback.

**Explain**

6. After testing, ask the design teams to reflect on the feedback by combining their data as a team onto the Testing Feedback worksheet. From this data, allow teams to spend time altering their drawings and specifically identifying what changes they intend to make in the next iteration of their prototype.

**Evaluate**

7. Hand out the Engineering Design Project Paper Rubric. Tell students that their next challenge is to summarize their process into a team paper. It is important that you help students process the rubric before they begin drafting their papers. As a teacher, you may choose to have the entire paper due at one point or you may have students turn individual sections in at different checkpoints during the process. Please adapt so that is works the best for your classroom assessment needs.

**You’ll Know You’re Done When...**

Students have collected user data and know how the data will affect change in the next iteration of their design. They are ready to either prototype, ideate, define, or empathize again.

**Suggested Connections to Specific Content Areas**- These will be further developed during the 2012-2013 school year as part of the pilot program.

*General Science* – Experimental design permeates all scientific disciplines. The process of creating an experiment and relying on a team for authentic feedback is not dissimilar to the process described above. You could easily have students design experiments to meet specific curricular goals (developed by you or the students) and then have the students run each other’s experiments and give feedback on
the effectiveness of the “design”. This also tests student’s abilities to communicate well – sometimes they create a great experiment but can’t communicate the steps clearly in a procedure. If you wanted to test your student’s presentation skills, you could do the above activity and have them present a mock procedure to partner teams.

_Biology –_

_Chemistry –_

_Physics –_

**Extensions**

- Have students test their products on **actual users**! Activities for gathering user feedback are very similar to the Empathize phase. Make sure students are gathering good data from the user as they experience their product. For a detailed look at how you might implement real world testing for your students, check out this “lesson plan”: [https://dschool.stanford.edu/groups/k12/wiki/d68d9/Real_World_Testing.html](https://dschool.stanford.edu/groups/k12/wiki/d68d9/Real_World_Testing.html)
  
  **NOTE:** if the same user experiences multiple iterations of a prototype over and over, they begin to give feedback on the improvements you have made instead of their needs from the original problem. Be careful with when and how often you seek user feedback. This relates to the talking point used to engage your students at the beginning of the prototype lesson – when might it not be a good idea to show a customer the prototype? Why do companies often not reveal their prototypes?

- Have your students do stress and strain testing with their CAD drawings. Not all CAD software is capable of this, but if you did CAD drawings in the previous step, it might be easy to do actual stress strain testing on the components of a design. This is a crucial engineering skill that your students would greatly benefit from.

- If your students are having trouble coming up with good testing scenarios, you can use this lesson to teach them how to create testing scenarios:  

- Will students also be submitting their project to an Intel ISEF affiliated fair? If so, then students may need to get Institutional Review Board (IRB) approval prior to any human testing and possibly have users complete informed consent forms. IRB approval is not required for projects where feedback received is a direct reference to the product, where personal data is not collected, and where the testing does not pose a health or safety hazard. For more detailed information: [http://www.societyforscience.org/page.aspx?pid=317](http://www.societyforscience.org/page.aspx?pid=317).

**Resources**

TeachEngineering.org:

Stanford’s d.school K12 Wiki:  
[https://dschool.stanford.edu/groups/k12/](https://dschool.stanford.edu/groups/k12/)
Testing Feedback

Based on the Feedback Quadrants you received from your peers, determine what the most useful information about your product was and answer the questions below.

1. What were the most important things that people liked about your design?

2. What were the most important things that people didn’t like about your design?

3. What were the biggest questions brought up regarding your design?

4. What brilliant new ideas did people have for your design?
Design Step 6: Test  

Based on Resources from the d.school K12 Wiki
Launch

“Speak clearly, if you speak at all; carve every word before you let it fall.”

- Oliver Wendell Holmes, United States Supreme Court Justice

Introduction

How do you make others care about your product?

For anyone to ever use a product that has been created, its designers must carefully plan an exciting launch. In today’s technology industry, there is no better example of how to do a direct to consumer launch than Apple. Every new Apple launch is treated like headline news, but it wasn’t always this way. When the Macintosh computer launched in 1984, Steve Jobs could not even get one magazine to care enough for it to be a cover story. That all changed when Apple used a dramatic and now infamous Superbowl ad that referenced George Orwell’s 1984 book. It went ‘viral’ long before YouTube even existed. The Macintosh was a great computer, but Apple still had to find a way to make people care.

Now that you have created a product you will have the opportunity to present your work many times and in many different formats. You will have to find a way to make people care. Each presentation should be a professional delivery of your work; however, each presentation is also unique in format and focus depending on the particular event and audience. One key factor to remember as you prepare each presentation, whether it be thirty-seconds or twelve-minutes in length, is to focus on the people more than the product. Emphasize how your design will benefit the user. You should create a compelling picture of how it addresses you engineering problem. At the end of the day, people care about their problems so you need to make them see how your device could improve their lives.

The Georgia Tech High School Inventure Challenge will be one opportunity for you to launch your product. You should use the attached project evaluation rubric to make sure that you have addressed all the criteria that judges will expect to see. If chosen to move on to the next level, you will have a chance to share your work with true innovators. First, you must craft a short video pitch for your project. As a team, decide what you’d say if you only had thirty seconds to explain your design. What would you absolutely have to say to get your message across? What visuals could help?

By the way, just because you are presenting your product doesn’t mean the journey is over! The design process continues. Customers will give authentic feedback and you, the designer, need to listen and respond. This is the empathy phase of design. You’ll then boil customer feedback into a deep, addressable need that you can design for. Is the handle too big? The team should ideate solutions, build a new prototype, resume customer testing, and create a better product. And so the cycle continues.

Furthermore, there is always a next step. Is your design something you could take to market? Could you get a patent for it? Is there the potential for you to start a small business? Could you combine your idea with someone else’s in the class to change the world? Dream big... the possibilities are endless.

Lesson Plan

Learning Objectives
Lesson 7: Launch

- Students will learn how to target their audience during presentations
- Students will communicate the results of the engineering design project
- Students will explore marketing elements that may support their product

Materials

- Georgia Tech High School Inventure Challenge Rubric
- Launching your Product Worksheet
- Video camera(s)—can be a camera phone or Flip
- Assorted Forms for entry into the GTHSIC @ Your School (depends on structure at the school to select winners)
- Clock or timers

Procedures

Teacher Prep

- Copy the Inventure Challenge Rubric for each student with the Launch Introduction on the back
- Copy one Launching Your Product worksheet per team

Student Activities

Engage

1. Have students complete the following warm-up question: Choose one item you use often (ie: bookbag, phone, shoes, etc.). How did you learn about the item? What made you want to buy it?
2. Ask for volunteers to share their answers. Lead a discussion that highlights key elements of marketing to the students. You could even challenge the students to create a list of criteria based off common themes from their answers.
3. Pass out the Launch Introduction and Inventure Challenge rubric copies to students.
4. Read the first paragraph together and show the actual Apple ad to them if possible (http://www.youtube.com/watch?v=HhsWzJo2sN4).
5. Tell students that they are going to be challenged to create a pitch video for the products from their engineering design projects.

Explore & Explain

1. Pass out the Launching Your Product Worksheet and review instructions with students.
   a. As students complete step 1, encourage student teams to brainstorm best answers using vertical whiteboard space, sticky notes, virtual whiteboard space, or other options.
   b. As students transition to step 2, emphasize that criteria 7 is ultimately what matters. There are great products that never get used because they couldn’t be communicated well.
   c. During step 3, encourage students to think outside the box for both location and content of their video.
Evaluate

(Note: This step may be done in a future class periods to allow students time outside of class to finish their videos)

1. Have a viewing party to celebrate this end point in the design project and show every team’s pitch video. Have students answer the following reflection questions on their own paper.
   a. Reflection Question 1: Which product best addressed its user needs? Why?
   b. Reflection Question 2: Which product is the most appealing? Why?
   c. Reflections Question 3: After viewing all the product pitches, would you change anything about your product pitch? Why?

You’ll Know You’re Done When...

Students have created videos that effectively communicate their product and can answer the questions included on the Inventure Challenge Rubric.

Suggested Connections to Specific Content Areas- These will be developed during the 2012-2013 school year as part of the pilot program.

Extensions

There are many competitions besides the Inventure Challenge, that students may be able to compete in during the Spring. Some of these competitions include:

- Georgia Junior Science and Humanities Symposium- [http://www.georgiacenter.uga.edu/ppd/courses/academic-special-programs/georgia-junior-science-humanities-symposium](http://www.georgiacenter.uga.edu/ppd/courses/academic-special-programs/georgia-junior-science-humanities-symposium)

Resources


- A paper from the Clinical Chemistry journal on how to use summaries to communicate results
Launching your Product

You’ve developed a product, but how do you communicate how awesome it is to others? As a team, consider the following judging criteria for the Inventure Challenge and develop a pitch video.

**Step 1:** As a team, brainstorm best answers for Criteria 1-6 and then write the group’s consensus.

**Criteria 1: Practicality**
- Identify the critical features on your product. Why?

What problem or need does your project address?

Why is your project important?

**Criteria 2: Knowledge Base**
- Describe the science you had to learn in order to do your project.

What science that you learned in school did you get to apply in doing this project?

**Criteria 3: Design Based Thinking**
- Describe how your final design is different than the initial design.

How did you use test data from your initial prototypes to inform design changes?

What issues do you still have left to address?
Criteria 4: Creativity
What alternatives are there to your product?

What makes your product unique?

Criteria 5: Marketability
Describe why someone will buy your product and use your product.

Describe how someone will use your product.

Criteria 6: Social Responsibility
What ethical issues could your project bring up?

How does your project address environmental responsibility?

How did you optimize the resources that you had to work with?

Step 2: Revise answers considering the seventh criteria.  
Criteria 7: Enthusiasm & Communication
Show me the enthusiasm you have for your product.
Communicate your project clearly using the format to your advantage.

Can you ever imagine someone asking you those questions? They would sound silly, right? Instead, your audience is expecting these elements to be a part of everything you communicate about your project. You should communicate clearly and with enthusiasm whenever you talk about your project.

As a team, go back and reflect on your answers for Criteria 1-6. Using a different colored
pen/pencil, revise your answers above (may attach an additional sheet of paper if needed).

**Step 3: Outline and create your pitch video.**

A. As a team, decide what is most important to include in your pitch video. Reflect on your answers to the question above and star key information.

B. Using the starred information, take turns ‘pitching’ your product. Have one partner time the other for thirty seconds and then switch. Discuss afterward what worked about each pitch.

C. Write and rehearse a script for your pitch video. Remember to focus on the people, more than the product. Emphasize how your design will benefit the user.

D. Film and edit a thirty-second pitch video for your product.