three tools for teaching design in your classroom—monday morning ready

by Tonya Isabell and Nathan Mentzer

The engineering design process is very involved, and it is easy to superficially treat some design steps by rushing through them.

During the process of engineering design, data is collected and analyzed to make informed design decisions (ITEEA, 2020). There are many different engineering design processes used in science and technology classrooms. The Engineering Design Process (EDP) provided by the Engineering byDesign™ curriculum and illustrated in Figure 1 organizes engineering design into a systematic process to guide students through the hands-on learning experience (ITEEA, 2011).

In the engineering design process, each step has a set of activities for students to complete, which will help lead to a viable solution for the design challenge. Problem definition is a critical, messy, and challenging first step in the design process that students often treat superficially in their excitement to solve a challenge. Students should use criterion and constrains to create optimal designs, which requires exploration of the problem and research in the design space (ITEEA, 2020). Currently, during problem definition, students are expected to restate the general problem description from the design brief to begin digesting the details of the design challenge. Since the general description explains the problem, many students try to skip this step or copy straight from the design brief. Simply copying or restating the problem does not allow the student to internalize the information and the student may not have a strong grasp of the problem they need to solve. The lack of knowledge often leads to student frustration and lowers the level of excitement in class. Similar

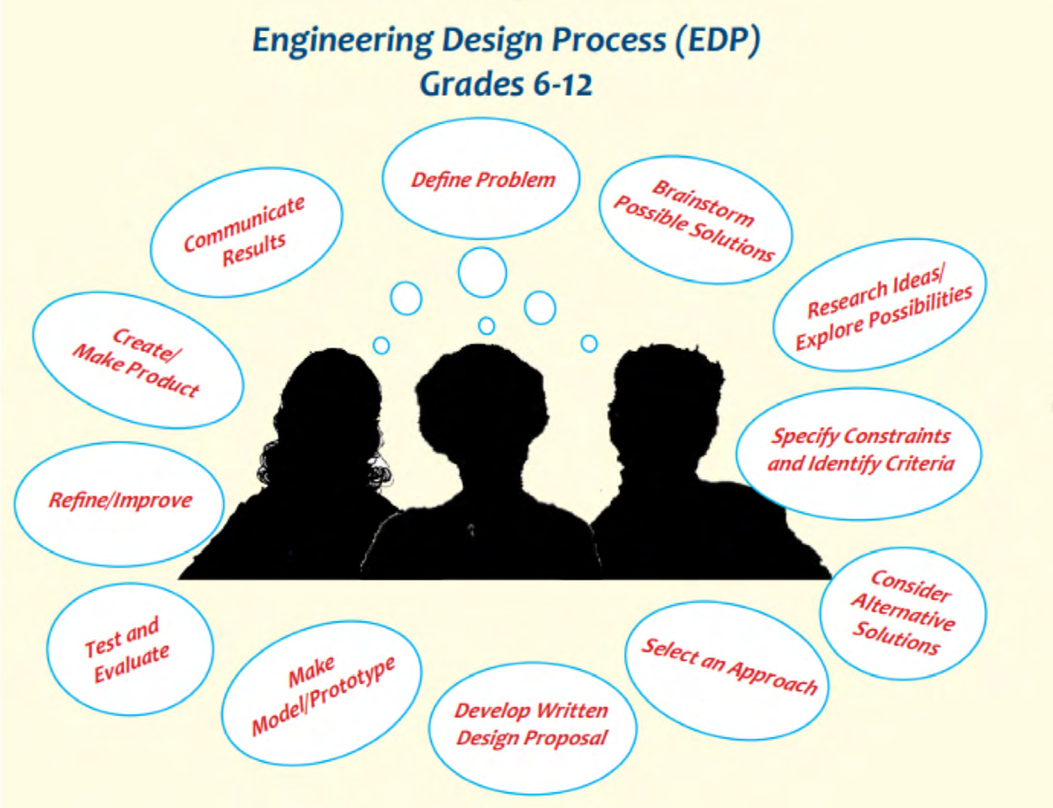

Figure 1
The Engineering Design Process (ITEEA, 2011).

obstacles arise during brainstorming ideas and exploring solutions. Students may find a blog online with a solution and step-by-step building instructions or just to meet the requirements of the assignment, they may copy information from the internet even if they do not understand what it means for their design work. This behavior also requires redirection from the teacher, which can lower student motivation. Adding a few more scaffolded pedagogical approaches to these initial steps of the engineering design process can help eliminate these obstacles and frustrations.

During the summer of 2019, the author began a PhD program at Purdue University and served as an instructor for Tech 120. Tech 120 is the introductory class to design thinking required of each student in the Polytechnic Institute at Purdue. The course includes English as a second language students, students without design experience, students of various ages and maturity levels, as well as students who request accommodations. Most days the author had to scaffold lessons, redirect misunderstandings, and modify time limits just as did high school and middle school teachers. During this experience, the author learned a few techniques that they wish they had known about as a high school teacher. These techniques added more structure to the first steps of the engineering design process and helped remove some of the ambiguity involved with the tasks. The students had a strong grasp of the problem space while developing their solutions which led to more successful prototypes. The purpose of this article is to share three strategies that give students additional guidance, reduce frustration, and foster the elation that comes with creating solutions and being ready to go on Monday morning.

Tool #1: Defining the Problem – Using POV Statements

"Design thinking is a non-linear, iterative process which seeks to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test" (Interaction Design Foundation, 2021). Engineering byDesign's engineering design process teaches design thinking in that it focuses on iteration, defining problems, and creating solutions. While teaching high school, many of the author's students thought the problem definition step was the easiest of the engineering design process because of the requirements for completion. Students received a design brief for each design challenge. The brief includes a general summary of the problem in paragraph form, a bulleted list of specifications, and maybe a diagram of the testing apparatus depending on the challenge. Students would read the general description from the design brief, then select the main idea and supporting statements. Using the information, they would restate the problem in their own words within two or three sentences in their engineering design journals. This strategy meets language arts and engineering and technology standards while supporting reading across the curriculum. As students used the engineering design process to solve multiple design challenges, defining the problem is a critical step to analyzing the problem, which requires greater exploration than restating the problem. The strategy supports language arts, but students still struggled to develop a deep understanding of the design challenge they needed to solve.

While teaching at the college level, instructors use a Point of View statement to begin problem definition, which may be a great tool to add to the engineering design process pedagogical strategies as it is a systematic process students can use to break down a design brief. "A good POV will allow you to ideate and solve your design challenge in a goal-oriented manner in which you keep a focus on your users, their needs and your insights about them" (Interaction Design Foundation, 2019). The point of view uses a formula, see Figure 2, "the user [descriptive] needs to [user's need] because [reason for the need]" (Interaction Design Foundation, 2019).

In a design challenge, the formula could help high and middle school students define the problem. The object/system _____ [what are you making] needs to _____ [what should it do] because _____ [how will it complete the task]. Figure 3 provides and visual of the updated formula and sample problem statements.

Using the POV format provides students with the opportunity to analyze the problem statement and break down the information provided. The POV format also provides an understandable guide for the next steps of the process. For example, during a discussion

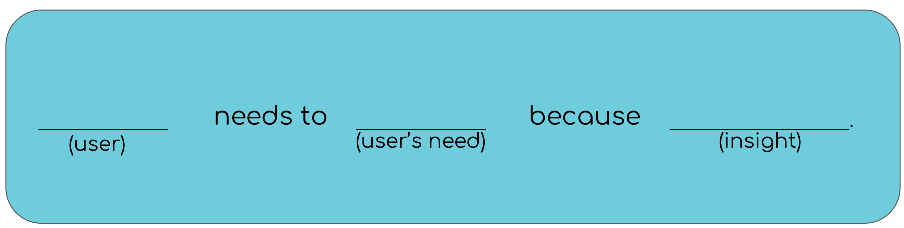

Figure 2
Point of View Formula

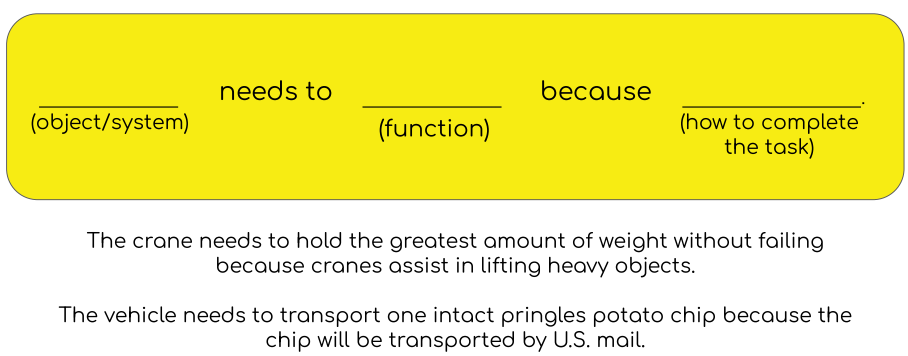

Figure 3
POV Formula for Engineering Design Process

of possible solutions, students can compare the ideas with the POV statement. Does the idea function as it should? Will this solution complete the task in the design challenge? Students can formulate their answers based on the information provided in the POV.

Tool #2: Brainstorming Multiple Ideas – Using a Fishbone Diagram

While problem definition is difficult, another obstacle many students have to overcome is brainstorming multiple unique ideas challenges. How many times have students stated: "but I already know what I want to make" at the beginning of a design challenge? This statement provides evidence of idea fixation, and it can be tricky to coax students out of idea fixation and it can lead to students having an unpleasant experience during class. Before coming up with different ideas in Tech 120, students complete a "fishbone" diagram. "A cause and effect diagram, often called a 'fishbone' diagram, can help in brainstorming to identify possible causes of a problem and in sorting ideas into useful categories" (Center for Medicare & Medicaid Services, 2010). Using the fishbone technique, students developed another level of understanding of their problem. Figure 4 shows a sample fishbone diagram from design thinking. The diagram starts with the "overall problem (fish mouth), the branches are the supporting causes of the problem (fishbones)" (Center for Medicare & Medicaid Services, 2010).

Students struggling to brainstorm multiple ideas may use this technique to diagram the problem. The diagram provides another opportunity for examination of the design challenge and analysis of the requirements for possible solutions. To adapt a fishbone diagram to the engineering design process, the object/system the student is creating becomes the mouth. The branches are the actions it must complete or the features the solution needs. The smaller branches are the things you need in your prototype to make sure the actions happen. Figure 5 shows a sample of the adapted diagram. The branches of the fishbone diagram drive the brainstorming session. When you develop a solution, look back as ask "does the idea have that part," or "will it complete that task?" The students move back and forth between defining the problem and brainstorming to come up with viable ideas.

For the solar car derby design challenge, the fishbone diagram includes all the criteria and constraints, materials, and requirements to solve this problem. Instead of using the method to analyze the causes of problems, students can use it to analyze different aspects of the challenge. The larger roots give the major segments outlined in the design brief. The smaller "bones" breakdown the major segments with specific information. The students use this diagram to drive the brainstorming step of the EDP as an organized checklist to evaluate and develop ideas. For example, if your solar car idea is taller than five inches, it will not meet the design requirements. That information is clearly laid out in the size section of the fishbone diagram.

Tool #3: Research – Observations and Interviews

No matter how hard the teacher tries; some secondary students will never get excited about research. The research step provides the opportunity for students to gather information about the design challenge and learn more about the obstacles they may face while developing a solution. Many secondary students assume they will go to the library and read books and write an essay on what they found during the research step as that is how they complete research in the traditional four core subjects. Allowing students to use the internet can make the research less intimidating while adding some entertainment value. Some students enjoy using the internet, while others may struggle due to the open-ended nature of the platform. Adding directed questions and guidance from the teacher is a popular method to differentiate this activity such that students have a well-defined idea of the functions of possible solutions. In the Tech 120 collegiate course, students used observations and interviews to enrich their research. Having secondary students' complete observations and interviews, in addition to literary reviewing provides differentiated methods to use while completing research on the design challenge.

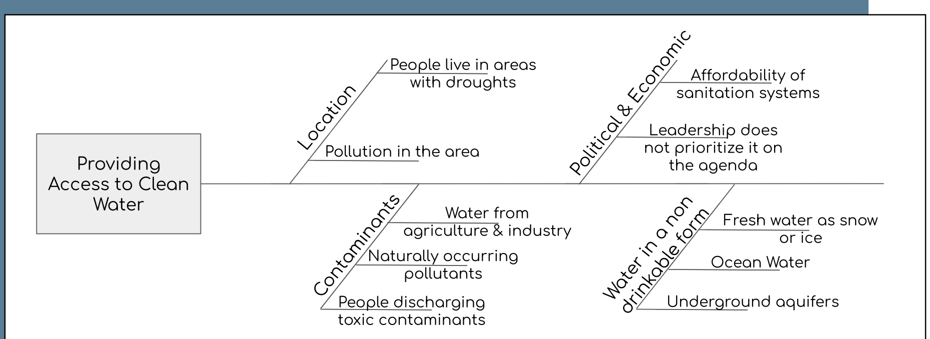

Figure 4
Sample Fishbone Diagram for National Academy of Engineering Grand Challenge

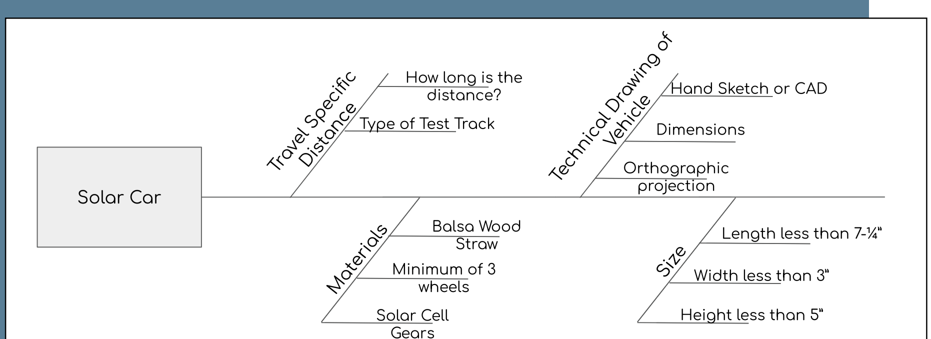

Figure 5
Sample Fishbone Diagram for Solar Car Derby

During the Tech 120 course, students observed the problem spaces where the end-user will utilize the solution or end-product. At the secondary level, each engineering design challenge is testing the different environments. For example, solar cars are tested outside while rubber band-powered boats are tested in a container of water. To implement observations, have each group observe the testing environment for the design solution using the "what, how, and why method." The what, how, and why method "is a tool that can help you drive deeper levels of observation" by documenting everything the student witnesses in the environment (Both, 2010). The observation should include not only the objects in the environment, but an explanation of how the activity in the environment is happening, and why the activity happens. For example, with a crane or bridge activity, the students observe the solution on the tester, how the tester works, and why the solution is breaking under the pressure. Students will see that reason for the specifications as they observe the solution being attached to the tester. This strategy will help cut down on solutions that do not attach to the tester and cannot be evaluated, thus cutting down on disappointment and frustration from students.

During an interview, a student could receive a first-hand account from an industry professional. In Tech 120, the undergraduate students were reluctant to conduct an interview citing that it was difficult to find someone or "what if the person is uncomfortable talking to the group." However, the students who were most comfortable were typically more knowledgeable about the design problem. One of the author's groups interviewed local doctors concerning the long wait times patients experience in medical offices. The doctor explained that the office gathers a large amount of information from each person, and some of that information is redundant for returning patients. The group developed a solution to give offices and emergency personnel instant access to patient medical history. While presenting, the students explained how the interview helped them develop their solution. Another group used an interview with the local homeless shelter to realize the major impact of substance abuse on homelessness. This group used this information to make positive changes to their prototype.

Many students prefer to use the internet for all their research and lean heavily on blogs and unreliable sources. Students copying straight from a website just to complete the research portion of the engineering design process do not benefit from the activity. Copying the information removes the research step from the engineering design process and does not support successful prototype development. Requiring students to complete an interview and/or an observation will reduce plagiarism through copying while motivating them to learn more about the design challenge presented.

Conclusions

The engineering design process is very involved, and it is easy to superficially treat some design steps by rushing through them. This superficial treatment not only jeopardizes student learning of good design thinking skills, but it also fosters a sense of busywork because students feel as though they are just checking boxes rather than engaging in meaningful work. The author struggled to develop strategies to scaffold students as a secondary Engineering and Technology Education teacher. The techniques: POV statements, Fishbone diagrams, observations, and interviews they began to use the summer Tech 120 course really increased their efficacy in teaching. The students expand their knowledge of the design challenge through extensive brainstorming and research. The prototype development step had more successful prototypes during the college course and that reduced student frustration and wasted time. Utilizing the strategies outlined in this article in your classroom can help students better understand the design process and develop successful solutions to future design challenges.

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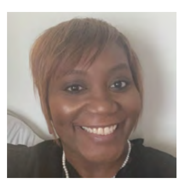

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