Innovation has been an important aspect of economic and scientific success in the United States for decades. Hobday, Coffey, Saalfeld, and Colwell (2011) suggested that, in order to produce innovative ideas, one must have a design-thinking mentality. This article provides the readers with an example of brainstorming techniques that have been implemented in industry and also reflect the practices used by Purdue University, College of Technology freshmen students while working through a design problem. The authors propose that these techniques, delivered to over 3,000 students in an introductory design course, have direct applicability to secondary students. This text will describe brainstorming processes used in Purdue’s College of Technology so that teachers may adapt and adopt these practices to their classrooms. The six brainstorming techniques are discussed along with how the students are evaluated in applying the techniques.

At Purdue University, the College of Technology students receive an education that is rooted in design. As part of a core curriculum, students take an introductory course, TECH 120 – Design Thinking in Technology, among other courses. TECH 120 students engage in the critical analysis of global challenges and related design problems. The course is similar to a high school engineering design course in that students also learn to take initiative in developing solutions by applying the principles of design. Specifically, this course applies a Human Centered Design (HCD) approach, which emphasizes understanding stakeholders, their needs and motivations, as well as impacts (positive and negative) of potential solutions on the stakeholders. Additionally, TECH 120 students apply mathematical, science, and technology concepts to solve design tasks. As an example, students engage in a sustainable design related to their college. Some student teams consider lighting in unused classrooms as a problem. To better understand the problem, students will identify and interview stakeholders, including students, faculty, maintenance staff, and security personnel, to discover why lights are left on. If they discover lights are left on for security reasons, they might consider alternatives that are less energy-demanding. If the issue is laziness and the last person to leave the room “forgot” to turn them off, students might consider motivational issues or prompting. Alternatively, perhaps the last person out assumes a new group of students will be entering the room shortly and leaves them on to be helpful, which might relate to information and communication issues. Each of these different scenarios has different sets of solutions and is socially constructed, which situates the design process as an interaction among stakeholders. This approach is transferable to ITEEA’s Engineering byDesign™ (EbD™) 12th grade Engineering Design curriculum. During the 36-week course, high school students also tackle design problems while applying design processes and principles similar to those of Purdue University students.
In teaching design, students spend time researching, developing, testing, and analyzing potential solutions while following design constraints and criteria. Design synthesis, iteration, and presentation are also similar aspects shared by Engineering byDesign™ and the College of Technology curricula. Students work in teams to produce documentation that properly defines a design problem, and group work will reflect real-world design projects. In order for students to develop solutions, they are taught a set of principles for brainstorming. These principles were developed for TECH 120 by an industry-based consultant and presented in a guest lecture that has been recorded and is publically available: http://vimeopro.com/cotpurdue/tech-120/video/47938742. In design education at Purdue, the TECH 120 instructional team believes that learning to develop innovative ideas through brainstorming is a skill that can be fostered, practiced, and improved with repeated experiences. Just like learning to ride a bike, students need education, practice, coaching and experience. The focus in TECH 120 is on the process in addition to the product, and credit is provided for attempting each of the techniques presented here in addition to credit for the results or products of brainstorming. Students document the results of their work, including the process they used to develop the ideas. They identify the technique they are attempting and the steps they pass through as they apply that technique.

The root of developing innovative ideas in any context stems from efficient brainstorming (Whitacre, 2010). Brainstorming has been utilized as a method of idea generation for years but was made popular by Alex Osborn in 1953 when he published the four original “rules” for brainstorming as shown in Table 1.

Design students and experts alike brainstorm to develop potential solutions to design problems so that new products and services can be created (Marshall, Coffey, Saalfeld & Colwell, 2004). According to Johansson & Woodilla (2009), the design process helps ideas become reality. Brainstorming is often identified as an early step in the design process and can be used to inform how a team should begin to understand stakeholders, what constraints should be applied to a design, what sort of interview questions should be created, and which prototypes should be chosen for further usability testing (Stanford Design School, 2010). Mumford (2000) suggested that not only does brainstorming start most design processes, it also helps a group determine which solution should be utilized. Brainstorming allows for students and experts alike to draw upon the knowledge of others, which helps in developing a sense of community and purpose among classmates and colleagues (Whitacre, 2010).

### Table 1. Brainstorming Rules as Suggested by Osborn (1953).

<table>
<thead>
<tr>
<th>Rule</th>
<th>Explanation</th>
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<tbody>
<tr>
<td>1. Go for Quantity</td>
<td>Come up with as many ideas as possible.</td>
</tr>
<tr>
<td>2. Avoid Criticism</td>
<td>Verbal and nonverbal criticisms should be suspended until the evaluation process begins (after brainstorming).</td>
</tr>
<tr>
<td>3. Welcome Unusual Ideas</td>
<td>The crazier the better; you never know where the train of thought might take you.</td>
</tr>
<tr>
<td>4. Combine and Improve</td>
<td>The idea that “1+1=3” means that combinations of ideas can lead to new and better ones.</td>
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#### THE BRAINSTORMING PROCESS FOR TECH 120

TECH 120 guest lecturer and industry expert Jason Tennenhouse has developed six techniques that allow collaborative groups to generate 100-200 ideas per day. In the TECH 120 course, students are required to brainstorm in groups, exploring potential solutions to two locally relevant design problems. Student teams were asked to watch a video that conveys the six techniques proposed by Jason Tennenhouse and then brainstorm 25 ideas while applying at least five of the techniques. Jason proposes that a brainstorming session should last roughly 30 minutes, a break should be taken, and then the session should be continued. This process not only focuses on generating ideas, but also the application of each technique through collaborative brainstorming to inform a design solution.

The students are evaluated using a rubric that has them demonstrate that they have developed the ideas and applied each of the techniques during the brainstorm. Elements of the rubric related to each technique are presented after the technique is introduced in the following paragraphs and are unique to each technique. Students are required to communicate their ideas through written description, sketching, or both. The students are also given a handout that details each technique and the submission required for the assignment (essentially a translation of each rubric element described in Table 2). Students are taught that they should produce innovative and unique ideas so that, in turn, their solutions will be innovative as well.
Mentzer, to adapt and document these techniques for classroom use. These six techniques are summarized in Table 2.

These techniques are meant to be either performed individually or collaboratively; it is up to the discretion of the group as to how these techniques are applied. Though the students are instructed to come up with as many ideas as possible, in TECH 120 they are only evaluated on generating 25 ideas from the techniques. The brainstorming process happens at two points during the semester, first during Project 1 when the students work on a design problem that focuses on Purdue University’s campus, and then on Project 2 where the focus is on Purdue’s College of Technology sustainability challenge. Both brainstorming sessions take place outside of class in groups.

**The Diverge/Converge Technique**

The Diverge/Converge method has a group focus on creating criteria that a design solution should follow and then by developing “wild” ideas in a series of iterative cycles. The criteria can be viewed as standards that the design should meet. By developing design criteria, the group can unpack all of the elements that a solution should be. Creating a list of wild ideas also allows a group to tap into their creativity and leverage the collective imaginations that could lead to something that may not have been thought of before. Kelley and Littman (2001) stated that creating wild ideas can send a group on a path that may uncover truly innovative ideas, though the focus should remain on the problem statement. After the criteria has been identified, a group should narrow the list of wild ideas that meet that criteria (converge). Once the list is narrowed down, the group should then diverge and expand the list of ideas that meet the criteria again. The included ideas should not be repeated ideas, but ideas that are focused on newer design criteria. Then the group can narrow down the list again based on ideas that meet the criteria. This process can be repeated as many times as necessary, narrowing in on a more functional solution.

In TECH 120, the students are required to submit documentation of their cycles of diverge and converge. The cycles are listed on paper for submission with a criterion and a broad set of potentially wild ideas that meet that criterion. A second criterion is listed. Ideas that meet both criteria are identified, and additional ideas are documented that meet both criteria. A third criterion is listed; ideas that meet all three are kept and identified, and new ideas are generated that meet all three. The rubric used for the Diverge/Converge process is comprised of the following checklist. Did the team of students:

1. List a series of wild ideas?
2. Identify a criterion?

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**SIX TECHNIQUES FOR BRAINSTORMING**

As previously mentioned, Jason Tennenhouse, through years of industry experience, has compiled a set of six techniques that are designed to aid in collaborative brainstorming. Mr. Tennenhouse consulted closely with course coordinator, Dr. Nathan Mentzer, to adapt and document these techniques for classroom use. These six techniques are summarized in Table 2.

These techniques are meant to be either performed individually or collaboratively; it is up to the discretion of the group as to how these techniques are applied. Though the students are instructed to come up with as many ideas as possible, in TECH 120 they are only evaluated on generating 25 ideas from the techniques. The brainstorming process happens at two points during the semester, first during Project 1 when the students work on a design problem that focuses on Purdue University’s campus, and then on Project 2 where the focus is on Purdue’s College of Technology sustainability challenge. Both brainstorming sessions take place outside of class in groups.

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1. List a series of wild ideas?
2. Identify a criterion?
3. Narrow the list based on ideas that meet the criteria?
4. Expand the list with more ideas meeting the criteria?
5. Identify an additional criterion?
6. Narrow the list based on ideas that meet the criteria?

The Decomposition Technique
The Decomposition Technique identifies individual functions required by a solution. Once all of the functions for an object are identified, the group starts brainstorming alternative ideas related to each function. Take for instance, a hammer. Instead of a group trying to reinvent new ways in which the hammer can be improved, think about all of the things a hammer does. A hammer can drive nails, hit other objects, pull out nails, or pry two things apart. The team then develops potential solution ideas for each function by addressing the question, “How else can we drive nails? Hit other objects? Pull out nails? Pry things apart? Establishing all of an object’s functions can set a group up for combining ideas in a unique and novel way. Additionally, groups can create maps to better illustrate relationships between similar concepts.

TECH 120 students are instructed to identify all of the functions of their design solution and then develop solutions for each of the functions. For evaluation purposes, the groups should list all of the design problem’s necessary functions and the solutions for each individual function. Depending on the complexity of the problem and solution, three functions may be appropriate as a starting point for practicing this technique. The rubric for the Decomposition process includes two items: Did the team:

1. Identify 2 to 4 of the functions needed?
2. Develop solutions for each function?

The Inputs Technique
For the Inputs Technique, brainstorming groups observe the environment around them—whether indoor, outdoor, or both. The inputs come from inspirations—a TV, the room itself, a parked car, a passenger, or someone walking, etc. While watching TV, you can challenge yourself not to switch the channel until you have a certain number of ideas or limit yourself to 2-3 minutes per channel. Inspirations can come from emergent solutions as well. For instance, if a group was tasked with developing a cool flashlight for children, examining a room with Legos in it could lead to a Lego figure flashlight with light coming out of its eyes. In addition to looking around your environment for ideas, it is a good idea to spend time reading magazines, books, websites, and utilizing other media to fill your mind with input outside of the brainstorming session.

As a requirement, students must record this set of ideas and also list the input with which the inspiration was derived. For instance, if a group came up with the Lego flashlight, the idea(s) should be listed and also a sketch of the flashlight should accompany the idea(s). A clear relationship should be noted, though, so students cannot simply make up an idea just to complete the task. This doubles as a good way to determine if the students are practicing the technique. Students can practice this technique individually to develop a list or work together watching the same television shows or reading the same magazines while collaborating with similar or differing ideas. The rubric for the Inputs process includes two items:

1. Look around you (could include TV, room, passenger in moving car, walking). List things or processes you see as they link to an inspiration.
2. Identify the new idea.

The Props Technique
The Props Technique calls for a brainstorming group to derive ideas from everyday objects. It works best if the prop is unrelated to the problem. An example could be a group faced with developing a new food access station at a University dining court, with a microwave as a prop. One possible idea could be that the food would be placed on a 10-foot-diameter rotating table that slowly turned and was heated (as a microwave does) as the students walked by to pick up the food. In a professional environment, the company could fill the room with props unrelated to the problem so that the group can draw inspiration from them. The technique works best if the props are different in terms of functionality; it helps the group think outside the box. Essentially, the props are there to help the group think of other ways to do the required task.

For the Props Technique, students are also required to record these ideas and identify the prop from which the ideas came. Similarly to the inputs technique, the relationship between the prop and the ideas should be made clear. The rubric for the Props process includes two items:

1. Find something in your space (room, house, etc.) that is unrelated to your problem and solution. Identify the object.
2. Use that object as the basis for the new idea. Identify the new idea.

The “Deck of Cards” Technique
The “Deck of Cards” technique can be performed in two different ways. One way is to create a deck of cards with functions for certain elements of your design problem. So if a team was
designing a new toy, the cards might have multiple images of joints and images of devices for making sounds, hinges, etc. If the team was stuck and not producing ideas, the cards could be shuffled, a few cards could be selected, and a product could be designed as a combination of the random draw. This process could be performed multiple times while adding new functions or more cards to the selection. Alternatively, a series of quick Google image searches could substitute for making an entire deck of cards. As an example, a design might be developed by randomly choosing a hinge from a series of pictures of different kinds of hinges and a latch from a series of different pictures of latches.

Students in TECH 120 are not required to create the cards to demonstrate this technique. Instead, they are instructed to do a Google image search and pull out some pictures and make a combination of different ideas. The image searches could include terms related to the design problem or unrelated terms. The combined pictures should be documented, and the resultant ideas, along with sketches, are required. Students can also do several image searches, pull one picture from each search, and then combine them into an idea as well. Similarly to the previous techniques, the relationship between the combined pictures and the ideas must be made clear. The rubric for the "Deck of Cards" process includes three items:

1. Do a series of image searches for a necessary element or dimensions of your solution such as hinges, color schemes, latches, shapes, etc. Screen-capture the image search page for each element of dimension.
2. Identify one of the resultant images from each of a few searches to be included in your idea.
3. Combine these into a single idea.

The Relaxation Technique
The last brainstorming technique proposed is called the Relaxation Technique. This was developed by realizing that often-times when the designer first awakens, his or her subconscious is most free and uninhibited—thereby allowing innovative thinking. These thoughts would then be recorded in a notebook. The authors realize that this technique may not be the most feasible while in a brainstorming group (or in class for that matter), though it can be useful outside of the class session on the students’ own time. Generally, students find it intriguing, and many will attempt it. In order for the technique to be properly performed, a system would need to be set up to allow the brainstormer to wake quickly after falling asleep. For TECH 120 purposes, instructors suggest to students that they put a chair on a hardwood floor (or equivalent) and sit in the chair while holding a spoon. Once they fall asleep, they typically drop the spoon and wake up. Their first thoughts upon awakening should then be recorded. This process can be performed as many times as necessary. As an alternative to this process, yet still leveraging the same subconscious free thinking, students may be instructed to relax their thinking about one problem and work on something else, thereby allowing their subconscious the opportunity to engage. In addition, students may be able to develop additional ideas between classes or overnight when they are not actively thinking about the problem at hand.

Though potentially unusual, this technique has been popular during the student brainstorming sessions because it can be a fun way to generate ideas. It is suggested that the technique be performed multiple times in order to generate as many ideas as possible. Because there is no way to clearly evaluate whether or not the students used the technique properly, it may not be one that teachers decide to require. It may be difficult to explain to an administrator passing by your classroom when he or she notices all your students trying to fall asleep in class. The rubric for the Relaxation Technique includes two items:

1. Stop working on your problem and relax (work on something else, go for a walk, try to fall asleep). Write the first idea down that comes into your mind when you are not actively engaged in this problem.
2. Identify what you were doing the moment before the idea struck.

CONCLUSION
Like a high school engineering design course, Purdue University College of Technology students take TECH 120 – Design Think-
ing in Technology, as part of a core curriculum. In this course, students apply the design process to two projects that involve University problems. During the projects, students are instructed to brainstorm at least 25 ideas in groups using the six techniques provided by industry design expert Jason Tennenhouse.

The six techniques include: (1) Diverge/Converge – include a list of wild ideas, narrow down the list to fit particular criteria, and then expand that list; (2) Decomposition – determine the individual functions of a product and develop ideas for new functions; (3) Inputs – use various kinds of media to fill your mind with inspiration; (4) Props – find unrelated objects in the working space from which to derive ideas; (5) "Deck of Cards" – create a set of cards with images that can be drawn to combine into an idea; and (6) Relaxation – fall asleep and then wake up so that the first thought can be recorded.

The authors believe that brainstorming is an essential skill that can be developed in young learners. College students generally agree that they have been asked to brainstorm before, but also agree that they have never received instruction on techniques or strategies. This article was to share six techniques that have been developed in an industry-based setting and refined over a period of three years with more than 3,000 college freshmen in a design course.

As with learning any new process or technique, initial experiences can be awkward and clunky, but with repeated practice and reflection the process gradually begins to make sense. In Tech 120, students practice ideation at multiple intervals during the semester to internalize the techniques proposed.

REFERENCES


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