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GIFTS: Dangerous Toys Project

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GIFTS: Dangerous Toys Project, by Daniel Harbowy

This Great Ideas For Teaching (and Talking With) Students paper details a project-based pedagogy for students taking "Introduction to Engineering." There are five motivating factors for this project. First, there lacked a central element to coalesce the coursework taught in the first engineering class students take. Second, getting new students to understand the engineering process is an important element of their first engineering class. Third, students with extremely diverse experience bases and abilitues all need to be engaged. Fourth, colleges with small engineering staffs need simple, yet engaging projects. Fifth, interest in engineering needs to be fostered among children in every community.

To address all these factors, I implemented a ten-week project that is simple, yet profoundly deep in its ability to motivate, focus, and prepare first-year engineering students for future coursework. It is also a project that can engage local elementary school students with STEM. I divided the project into 6 phases: Research (two weeks), Brainstorm and Analyze Potential Solutions (two weeks), Develop Models (three weeks), Test Models (two weeks), Implement and Commercialize (one week), and a Competition at the end of these ten weeks.

Background: On day one of my Engineering 101 class, I introduce myself as the CEO of a fictitious company, Dangerous Toys LLC. The company mission is to "develop toys that encourage Science, Technology, Engineering and Mathematics in children." The company vision is to "enable children of all ages, genders, ethnicities, and abilities to engage in STEM in innovative and fun ways." Each class is assigned a toy they must build, which meets specific criteria. These toys are fairly simple, like mouse trap cars, rock skippers, trebuchets, pressure rockets, or hot air balloons. The differences between these projects, and something typical High School students may do, are the specific criteria students must meet, and the engineering processes they must apply. Some unique criteria I use include are: making the designs wheelchair accessible (one student was a quadriplegic), reducing the size of the package the device must "shipped in," providing instructions for teaching STEM principles to kids, or adding specific performance criteria (like distance, height, accuracy, time or angle). The criteria also have competing requirements and tradeoffs. For instance, cost must be minimized, but durability must be maximized; or size/weight must be minimized, but power must be maximized. The criteria are laid out in a Request for Proposals (RFP). Here is a sample RFP for a pressure rocket:

- Design can be assembled/used by a child 8+ years old, and is in a wheelchair (Describe how you will make it easy to assemble and operate it in less than 5 minutes…2 pts)
- Toy must encourage Science, Technology, Engineering and/or Math (Describe how you will make it so the device can change the angle and power…2 pts)
- Toy costs less than $20, based on 1000 units (Specify costs for individual parts…3 pts)
- Rocket must launch 20 and 40 feet (Describe how you will generate power…2 pts)
- Toy must weigh less than 5 lbs. (Describe how you will optimize materials used…2 pts)
- Toy must be reusable (Describe how you will ensure the toy will be durable so that it does not easily break, fall apart, or warp…2 pts)

Assessment: Students are first given two weeks to conduct the "Research" phase of the engineering process. In this, they craft a two-page proposal of the design they will implement. The first page is a written description of how the project will meet the RFP criteria given, and the second page is a sketch of the proposed system. This step gets all the students to research possible solutions, come up with their own ideas, and articulate what they think will work. By doing this, students engage in the first three steps of the engineering process: identify the problem, define the problem, and research/gather data. Students are then placed in teams of three to four (typically eight to nine teams), and are each assigned one of the following roles: Project Manager, Mechanical Engineer, Industrial Engineer, or Materials Engineer (optional).

Responsibility for the next phase of the project falls to the student with the Project Manager role. They spend two weeks leading the "Brainstorm" and "Analyze Potential Solutions" phases of the engineering process. The Project Manager takes the four ideas the team came up with, facilitates a discussion of new ideas from their research, lays out pros and cons of all ideas, and then decides on what the final design will be. The Project Manager then writes a two-page paper detailing the pros and cons of designs they chose or discarded, and reasons for doing so. They also provide a final drawing of the design chosen. Students are graded on the following criteria:

- Lay out all assumptions (Were all key design requirements considered; were engineering principles used, were limitations identified…6 pts)
- Other ideas considered (What ideas were not used and why…6 pts)
- Why the ultimate design was selected (What advantages does this design have that will set it apart from the competition…6 pts)
- Sketch (Does the sketch incorporate all the key features of the design showing scale, and indicating moving parts, with believable results…6 pts)
- Quality of proposal (Correct spelling/grammar, logical flow, ease of reading…6 pts)

Responsibility for the next part of the project falls to the student with the Mechanical Engineer role. They spend the next three weeks in the "Develop Models" phase of the engineering process. They take charge of the actual build, must write a paper on what challenges they encountered in producing the design, and detail how they overcame the challenges. It is made clear to the student with the Mechanical Engineer role that they do not actually have to build the device, but are responsible for ensuring the build happens, and documenting the challenges and roadblocks the team encounters. Among the 64 teams I have taught over the last eight years, I have yet to have a team that did not encounter challenges, and had to modify the original plan the Project Manager proposed. It is important that students learn to expect challenges and persevere to find solutions. Students are graded on the following criteria:

- Resources (Was a comprehensive parts list developed…6 pts)
- Cost estimate (Was an updated cost estimate developed based on 1000 units…6 pts)
- Challenges (As the project was created, what challenges/roadblocks were encountered and how were they overcome…6 pts)
- Detailed operation description (Was a description of how this system is to be operated made clear, including safety features, environments, and limitations…6 pts)
- Quality of proposal (Correct spelling/grammar, logical flow, ease of reading…6 pts)

Responsibility for the next part of the project falls to the student with the Industrial Engineer role. They spend the next two weeks in the "Test Models" phase of the engineering process. Students are introduced to basic design of experiments methods and must create a full-factorial design, test the product under each of the conditions, record the results, and create graphs/charts that detail the results. Students are graded on the following criteria:

- Charts (Clearly explain the test results with properly labeled axes/titles…7 pts)
- Minimum of 10 test events (Consistent, repeatable runs conducted…10 pts)
- Accuracy/Range measurements (Logical and quantifiable test methods/results…10 pts)
- A final cost based on 1000 units (Specify costs for individual parts…3 pts)

Responsibility for the last part of the project falls to the student with the Materials Engineer role. They facilitate the "Implement and Commercialize" phase of the engineering process. While their tasks can be worked on throughout the project, they have one week to finalize their presentation. They create a detailed set of construction/operating instructions, give the project a finished look, and give a pitch to sell their product. Students are graded on the following criteria:

- Pitch (A 2-3 minute summary on why their design is the best one to produce…6 pts)
- Graphics (Have a team name/logo, and show the design and build process…4 pts)
- Present Data (Were test results and final costs presented clearly and concisely…10 pts)
- Operating Instructions (Was assembly/operating instructions clearly described…6 pts)
- Quality of Presentation (Correct spelling/grammar, logical flow, understandable…4 pts)

The project culminates week ten with a competition, where each four-person team competes for the best design. Students are graded based on whether or not they met certain minimum criteria. While oftentimes they far exceed these criteria, the focus of grading is on a clear demonstration and application of sound engineering principles. From a competition standpoint, I have shown below a sample scoring sheets I used to rank the teams for the pressure rocket:

Low score is best	**Team 1**	**Team 2**	**Team 3**	**Team 4**	**Team 5**	**Max**
Size (dimensions exceeded)						5
Colors/style (teams ranked)						5
Kid appeal (teams ranked)						10
Ease of use for a person in a wheelchair (teams ranked)						10
20' distance (add miss dist)						10
40' distance (add miss dist)						10
Max distance (teams ranked)						10

Community Impact: Sometimes I involve local elementary school children in the testing process. For the project on the pressure rockets, I brought my engineering class to a fifth grade class. One fifth grade student was in a wheelchair. My students saw first-hand the importance of accessibility in their design. The elementary school teacher was so excited about the project that she continued to teach this in her classes and expanded to other simple STEM projects. For a trebuchet project, I brought my nine-year-old daughter to the college. When she struggled to assemble some projects, my students learned the need for simplicity in their designs.

Concluding Thoughts: This project-based curriculum meets the objectives for an Introduction to Engineering course. For many colleges, that description is similar to this:

"An introduction to engineering, its evolution, methods, and ethics. An overview of various engineering disciplines and curriculum requirements, an introduction to a variety of modeling and analysis methods, written and oral communication activities, discussion of professional ethics and social implications of engineering work."

"Engineering methods" are learned by the application of the engineering process throughout the project. An "introduction to a variety of modeling and analysis methods" is learned through brainstorming, analyzing potential solutions, and designing experiments phases. Students develop "written communication skills" through the two papers they must write for this project. Students develop "oral communication skills" by coordinating with their fellow team member and giving their presentation at the end. Students learn about the "social implications of engineering work" by thinking about and seeing the impact their projects can have on kids. Finally, students discuss the "ethics" of using parts from a kit or existing toys on the market, as that would result in copyright infringements.

Here is a typical sampling of comments I have received from students over the past 8 years: "My favorite part of this class is the final project, it engages you in a group, it's fun, competitive, and plenty of time." (Fall 2016) "I liked that we got to build a rocket…it gave me an idea of what it takes and the things engineers do on a small scale." (Fall 2017) "I liked the idea of basing most of the class around a core project and showing the importance of analysis in creating an engineering project." (Fall 2018) "One of the things I liked about this class was the capstone project because (of) the various requirements that were involved and that it went over the entire term. From what I learned from the book it seemed to represent, as much as it could, what a real project would be like in real life. It involved working with other people, working around problems that had to be outsourced in the real world." (Fall 2019) "It was great to get my hands on the project and see how engineers think and work out problems. Overall, I learned a wide breadth of knowledge from this class, and I feel better prepared going forward into more engineering classes and, hopefully, a career." (Winter 2020) "He also used a great method of grading group projects. We worked as a group, but everyone received a grade for the portion that they were responsible for." (Fall 2021) "I really liked the team aspect of this class. I think it's really helpful to learn how to work in a team in order to be successful in future jobs." (Fall 2022)

These projects are simple enough that they can engage all students…from those with no engineering experience to those with significant amount of experience. Also, these projects can be used to engage children of all ages and abilities throughout the community. Finally, these hands-on projects are really fun, and teach foundational engineering skills.

If you wish to see some of the other projects and rubrics I have used in this class, I have made all of my materials Open Education Resources. You can find all of these on my website by scanning the QR code to the right.