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Hands-on Project Based Learning on a Shoestring Budget: You Don’t Have to Buy a Robotics Kit

Abstract

In the “Introduction to Engineering” course at Austin Community College core learning objectives were met through a series of hands-on team projects. The author adapted these projects from various sources to make this first taste of engineering an engaging experience for the students. This paper focuses on the first major group project wherein the student groups went through the engineering design process up to and including the creation of a functioning prototype of their designs.

The author supplied materials and class time for the completion of the project, although the students were allowed to incorporate materials they brought in and/or to work on their projects outside of class. In addition to describing the project challenge, materials provided, and the resulting student creations, this paper will discuss the results of a survey that the students completed regarding this project. The survey was completed for extra credit on a midterm exam and crafted to assist the author in refining the project for the next time the class was taught. The survey assessed the materials used during the course of the project in addition to the students’ attitudes towards the project. Although the materials cost about $100 for the initial implementation of this project, many of the supplies were plentiful enough for use in future projects. Therefore, the cost per student over several semesters would be less than the approximately five dollars per student expended here. The purpose of this paper is to share this experience with others who are seeking to create project based learning opportunities without using specialized laboratory space and with limited financial investment.

Introduction

At Austin Community College in Austin, TX, the “Introduction to Engineering” course helps students explore engineering through several different instructional styles, including group projects. This paper focuses on the first group project that the students in the author’s section completed. The paper will include discussion as to the learning objectives covered by the project, a description of the project, an example of student projects, and results of a survey about the project that the students completed for extra credit on their midterms.

About Austin Community College

Austin Community College serves the greater Austin metropolitan area, including communities in the surrounding counties that have voted to be a part of the community college district. At time of publication, ACC has eight campuses and eleven centers offering classes. The distinction is that the centers are open for restricted hours such as for evening classes only, whereas the campuses operate as full time college campuses. Of these seventeen locations, five campuses host engineering classes\(^\text{1,2}\). Although Statics, Dynamics, and Mechanics of Materials are offered at an even more restricted number of campuses (one to three), the Introduction to Engineering course is offered at the five campuses with an engineering presence\(^2\). Due to the distance between the campuses, cost of robotics kits, and lack of storage at some locations, it is
not practical for a class set of LEGO Mindstorms robotics kits to be maintained for all of the campuses. Further, engineering classes are scheduled for standard classrooms (versus physics laboratory space). The group projects assigned by the author therefore were constructed without specialized facilities and small enough to be stored in the corner of a janitor’s closet (where the department was able to negotiate for a little storage area for this class).

**Prototyping Project**

The first group project required the students to engage in the engineering design process through the initial prototype phase. The inspiration for this project came from a paper presented at the 2010 ASEE Annual Conference in Louisville, KY. That paper was on a freshman level innovation class taken by non-engineering majors at the University of Texas at Austin. One of the group projects described in that presentation and paper had the students learn about the engineering design process and build an assistive device for wheelchair-bound people\(^3\,^4\). The project concept seemed ideal, however the parts list was a bit expensive for the author’s budget. The University of Texas at Austin had spent $51 per team for a total of $510\(^4\). The author needed to keep the cost of this project to about $100 for the entire class. To reduce costs, the author reduced the number of items in the kit versus what was listed in this paper. Items that were eliminated from the kit included all of the electrical products, foam core board, pencils, engineering paper, knives, and angles.

**Project Details**

The prototyping project required the students to use the engineering design process. While there are many forms of this process, this project had the students develop a project mission statement, assign team member roles, identify customer needs, develop a grading rubric for ranking how well ideas met the customer needs, brainstorm ideas to address the problem, organize the brainstorming through some additional idea generation techniques, finalize the prototype design with a sketch, and then build an operating alpha prototype. The final design sketch had to be shown to the author to receive the prototype building materials as a control mechanism. A few groups had not carefully read the project statement and thus were designing something other than the intent of the project. By talking with the groups about their project design at the sketch stage, the author was able to re-direct the students towards the project goal before the teams spent time constructing their projects.

The project assignment listed the functions that the prototype would have to be able to complete, elements of the design process that should be included in the design report, and an overview of expectations for the final presentation. Through these three components, the project was a key part of how the class met three learning objectives for the course:

- “Use technical communication skills to explain the analysis and results of introductory group projects and exercises in engineering and computer science;”
- “Explain the engineering analysis and design process;” and
- “As part of a team, design a simple engineering device, write a design report, and present the design.”\(^4\)
Two class days were provided for the students to work in class on the projects. The intent of providing class time was threefold: so that substantial completion of the project could occur in class; for the students to have access to the professor for questions while they worked; and to assure that these students (many of whom worked in addition to attending community college) were able to meet with their assigned groups. As can been seen in Figure 1, the working space for the groups was a standard classroom with tables and chairs. No machine room or laboratory equipment was made available to the students.

**Prototype**

The particular design challenge was borrowed from the previously cited innovation class: design a hand-held assistive device to allow a wheelchair-bound person to interact with a walk-up (standing height) ATM. Entering a PIN on a standard keypad, retrieving cash, and both inserting and retrieving a bank card were the tasks required to function on the group’s prototypes. In earlier discussion of prototyping the class had learned that only key features functioned on early engineering prototypes, which was the concept used to choose the list of functions for the project. As such, appearance was not important to the grades, although several groups tweaked their prototypes to have a sleek appearance.

**Design Report**

A design narrative formed the basis of the project’s design report. The groups described how they used the engineering design process to develop their prototypes. The project statement listed certain elements of the design process that were required to be included in the report, but allowed the students to decide which elements should be in the body of the report versus an appendix. The groups typically did well on the design report, but it was obvious that there should have been more discussion about what is meant by a “design narrative” prior to the assignment. The term came from the author’s industry experience in structural engineering design and, in that context, refers to a prose document, which is submitted to the owner of a project, outlining the design challenges and decisions made by the structural engineer. In an extreme example, one group submitted a report comprised only of bulleted lists of the required items without including any prose to explain why these items were written on a sheet of paper.

**Presentations**

Although power point presentations are abounding in industry and academics, this group project forbade the use of power point. In business it is important to be able to construct a persuasive argument without relying on prepared slides as a crutch, such as with the case of the anecdotal elevator speech. Another group project focused on the use of power point, but this project
pushed the students to be more creative in visual aids. While all of the groups demonstrated their prototypes (as seen in Figures 2 through 4), only one group used an additional visual aid (writing on the white board). Although the author hopes that the students’ future technical communication courses cover presentation skills in greater depth, the lack of creativity in the presentations lead the author to conclude that more direction was needed for the students to understand expectations.

Student Creations

Mousetraps, rubber bands, pipe cleaners (chenille sticks), PVC, wooden dowels, nylon string, clothespins, paper clips, and glue sticks were among the supplies provided to the groups. The complete list of materials provided is in the appendix, but the preceding list serves an illustration of the low-cost, readily available supplies that can be used to build prototypes. From the wide range of approaches used by the groups to solve the same project with the same base material set, it was evident that the students did not lack for creativity. Figures 2 through 4 show students demonstrating their prototypes as part of their project presentations. These three photographs are representative of the variety of solutions the students devised. The author allowed students to bring in additional items to use in their projects, and thus some of the project incorporate items that will not be on the parts list. For instance, the group that developed the mousetrap-based device in Figure 3 used a length of 2x2 for their main structure. Another group came up with an idea, through design by analogy, to use the mechanism from a self-opening umbrella in their device. Although the self-extending feature that they desired was not required to function for the project, they viewed it as a key design feature. Thus, this group used an umbrella as the base of their prototype as seen in Figure 4.
Survey

While the author thought this prototyping project was a great idea, student feedback was needed for confirmation. In addition to student perceptions, the author was curious as to which materials were most useful or least useful to the groups. These queries were used to craft a brief online survey for the students to complete. Student participation was high (89%) as extra credit was given on their midterms for completion of the survey. The five points on their midterms was the size of the curve that the author intended to apply to those grades anyhow. The primary intent of the survey was to assist the author in tweaking the project for future use.

Survey Description

The survey consisted of seven statements that the students evaluated with a Likert scale, an evaluation of what prototyping materials were used out of the provided materials, and five short answer questions. There were five possible selections for the students to choose to evaluate the seven statements: from strongly agree, through neutral, to strongly disagree. The seven statements were:

1. The instructions for this project were clear.
2. Too much class time was spent on this prototyping project.
3. This project has helped me gain a better understanding of the engineering design process.
4. I felt engaged in this project because the prototype was designed to help someone in need.
5. The prototyping project should be included in future versions of this course.
6. I enjoyed this project.
7. I enjoyed using the prototyping design kit to make the ATM card retriever.

The material evaluation was a series of simple check boxes. Each material in the prototyping kit was listed with the possibility of the students checking one of two boxes to indicate that they had or had not used that material in their prototype.

Of the short answer questions, two were continuing to look at the materials that the students used in their prototypes and three requested the students’ opinions on the project and the engineering design process. These questions were:

9. What materials did you wish were in the prototyping kit?
10. What materials did you use in your prototype that were not in the prototyping kit?
11. What concepts do you feel that you learned by completing this prototyping project?
12. What elements of the engineering design process did you find the most helpful?
13. What elements of the engineering design process did you find least helpful?

Survey Results

Of the sixteen student responses to the survey, fifteen were used for this analysis. One student’s responses were disregarded because that student did not participate in the prototyping project. Figure 5 presents the students’ responses to the seven statements in the survey. While the
responses are presented as percentages of the total response received, the number of respondents for each category is listed on the correlating bar. Overall the results were very positive, with 80% of the students reporting that they enjoyed the project and only one student not enjoying the project. The response for enjoyment of making the specific design challenge was not as enthusiastic, but still largely positive. In the short answer section one student noted that they would have preferred to pick their own prototyping challenge, rather than all groups solving the same challenge.

**Figure 5: Survey Responses Using a Likert Scale**

As two lectures of class time were dedicated to the students’ work on the project, the second statement was intended to gauge whether it seemed like too much time had been allotted to the project. Although one student thought that too much time had been spent on the project, most did not. The author is not surprised by these results as one might expect that time working on a project can be comparatively more exciting than a standard lecture. Also, the phrasing of this statement (where a ranking of disagree is the favorable result) was included to check if the students were reading all of the questions versus blindly checking “agree” throughout. While one student was neutral on the topic, over ninety percent of the students recommended that this project be included in future classes.

The third statement, which pertains to whether the students felt that the project helped them better understand the engineering design process, indicates most students (87%) found this hands on project to be helpful. There were two students who were neutral, but no students felt that the project did not help them better understand the design process. While this statement did not directly measure the students’ ability to meet the course objectives of explaining the engineering design process, it did show that the project helped them to better understand the process, which should in turn help them explain the process during testing. From the short answer question regarding what concepts the students felt they had learned by completing the project, the answers
were all positive. Some students noted they had learned better time management and how to work more effectively as a group. Two representative responses were:

“I learned how to incorporate everyone's ideas into the prototype and how to improvise with limited materials, this project really teaches you how to be creative.” and “For me, it was less about learning anything new than putting theory into practice. The textbook/lectures already covered Gathering Information, "First Cut"s, and Revision, which are simple to grasp, but the Projects give a sense of what can get done in a given amount of time, how easy/difficult it is to actually apply those steps to a real problem, and (especially) what setbacks can occur in the process and what the end result (not just the prototype but the written work too) will look like.”

Two of the short answer questions asked what elements of the design process were most or least helpful to the students during the project. It was interesting to the author that both questions yielded very similar responses. Two methods for organizing brainstorming, mind mapping and 3-6-5, as well as documentation were listed as being both the most and least helpful elements of the design process. Other than one student who listed documentation as both most and least helpful, the students often were choosing sides between the mind mapping and 3-6-5 methods (finding one to be most helpful while the other the least helpful). The author sees these varied responses as indications that they students now have some design experience and are beginning to develop their preferred design style.

Figure 6 shows the students' reported use of the prototype kit materials. The chart presents the use of each material in the kit as a percentage of total response and with the number of responses listed on the corresponding bar. As can be seen from the graph, there were no materials either universally used or disused in the kit. This range of usage indicates to the author that the kit contained a reasonable mix of materials to allow the students flexibility in creating their prototypes. The least used item, quart-sized zip-top bags, were used by each group to contain the kits’ loose items such as paper clips, rubber bands, and popsicle sticks. The one student indicating their usage probably was referring to this storage capacity, because the author did not observe any prototypes that incorporated these bags. Similarly, each group was given a trash bag to store their prototype kit parts (and in progress prototypes). The most popular items involved PVC as most groups used PVC pipe as the main structure of their devices.
The PVC cutters were not provided to each group, but instead the author provided three pairs for use during class. From the author’s observation during the project, it would have been useful to also provide scissors and a stapler. These tool type materials need not be purchased for each group, but a few of each can be used for the entire class (and for many future semesters). In the short answer section of the survey most of the students (nine of fifteen) did not have any additional items that they wished were in the kit. Items that were listed on the wish list included screws, scissors, Velcro, and a smaller diameter PVC. From the question asking the students what additional materials they supplied to complete their prototypes there was a wide range of responses. One group based their design on an umbrella, and thus used their own. Another group used a length of 2x2 wood instead of PVC for the main structure of their device. Additional items provided by the students included brake cable, screws, super glue, Velcro, metal fasteners, colored tape, and a toilet paper roll.

**Summary and Conclusions**

As part of an introduction to engineering class, group projects were used for students to engage in the engineering design process. The first group project involved the physical construction of a crudely function prototype, a written design report, and oral presentations. This project helped the course meet core learning objectives and engaged the students through hands-on participation.

The total budget for the project was roughly $100, which resulted in an expenditure of about $5 per student to supply the materials. While most of the PVC and wooden dowels were incorporated into these projects, many of the materials were plentiful enough to use in many future classes and/or for more students in a course. Thus, the cost per student could be
significantly reduced if more groups shared these extra materials, such as rubber bands, string, clothespins, and glue sticks.

The survey showed that the students generally enjoyed the group project, and that they definitely got to experience the engineering design process by completing the project. Their experiences included learning about time management, the dynamics of group work, and their preferences for developing ideas out of brainstorming sessions.

The author hopes that other educators will take the information presented in this paper and develop hands-on projects to engage their students’ interest in engineering. The students in the author’s class enjoyed themselves and learned about engineering design without using robotics kits, which allowed a small material budget to accomplish big goals.

References

Appendix

ENGR 1201: Group Project #1
Design Process through Prototyping
Due Monday, February 21st, 2011

General:
Your group will design a device to help the wheelchair-bound use a standard walk-up ATM.

There are three elements to the project’s final grade:
- Design Report 50%
- Prototype 30%
- Presentation 20%

Prototype:
Being able to complete tasks such as using an ATM without assistance from another individual is part of independent living – plus, would you trust a stranger to handle your ATM card, cash, receipt, and input your PIN? Therefore your solution must involve the final user and your device, but no additional people for your device to work. Note that your device must allow the user to insert/retrieve an ATM card, retrieve cash and a receipt, and to input a PIN. You may assume that there is a standard keypad on the ATM for entering information (you do not need to interact with a touch-screen).

Time and materials for creating your prototype will be available during class on February 14th and 16th. Your group may also use the in-class time to write your design report and prepare your final presentation.

Design Report:
Write a design narrative for your design report. You should describe your final prototype and the following items, which may be split between the narrative and an appendix. For instance, your mind map and 3-6-5 documentation would be appropriately placed in an appendix.

- Mission Statement
- Identify what customer needs you focused upon
- Metric/grading rubric
- Mind map
- 3-6-5 documentation
- Sketch of design concept your group selected to prototype
- Team roles defined
- What would you do next?

Presentation:
Each group will have eight minutes to present. Of this time six minutes should be a prepared presentation and two minutes will be reserved for questions.

Note: Power Point will NOT be allowed for this presentation. You must use your prototype as one of your visual aids during the presentation.

Figure 7: Project Assignment
Student responses to the short answer questions:

9. What materials did you wish were in the prototyping kit?
   - None really. I felt that there was an adequate variety of supplies to accomplish the task. I feel that constraints can fuel creativity more effectively than limitless resources.
   - It was a good starter kit. Its impossible to encompass all materials.
   - plastic
   - smaller diameter pvc as well as the large.
   - screws and screwdriver
   - i think everything that was needed was in the kit.
   - Self tapping screws 3/4" in lenght.
   - I believe we were provided enough material.
   - some sort of velcro
   - We pretty much had everything that we needed, maybe just a little more of everything I remember running out of PVC connectors
   - scissors pliers
   - I felt it was a fairly well rounded kit for the task.
   - Nothing further. Everything we considered using was either already present (duct tape, string, etc.) or was a component in something provided (the spring off the mouse trap). I can say that, upon seeing the materials, it became clear that all groups were likely to produce a similar prototype.
   - i thought the prototyping kit was great. i just thought the idea of making an atm retriever for the disabled was a bore. there are so many things to improve out there. just like the project we just finished. i would say let people decide what kind of prototype they want to make.
   - none

10. What materials did you use in your prototype that were not in the prototyping kit?
    - Extra strength mounting tape - Misc. hardware (2 screws 2 bolts) - Super Glue
    - Wire, toilet paper roll, speaker, circuit card, umbrella.
    - wood
    - None
    - bicycle brake cable and various metal fasteners
    - we bought different toys and combined some parts like springs
    - 2x2 wood stick
    - Plastic velcro -Super glue -2X2 piece of wood
    - Nothing we used everything from what was supplied in class.
    - umbrella
    - a toy with and actuating arm and metal rod
    - toilet paper roll (handle grip), some yellow tape (Don't recall seeing that; could be wrong), the Umbrella itself, musical greeting card (the "mp3 player"), electrical wire (wiring the "player" to push button), cardboard (the button itself)
• we went and bought some jaw clippers.
• None

11. What concepts do you feel that you learned by completing this prototyping project?
• How to build a prototype from start to finish.
• The Design Cycle
• I feel I learned a good basic overview of each step in conceiving, designing and building a prototype.
• the design process became much more clear and I gained a better understanding of the actual job of designing something
• mindmapping, working in a group
• Effective Team working and Management.
• I better understand the prototyping process, the mind mapping process, and the 3-6-5
• I learned how to incorporate everyone's ideas into the prototype and how to improvise with limited materials, this project really teaches you how to be creative.
• how to better time manage and find a way to work around people's schedules
• problem solving, documentation
• For me, it was less about learning anything new than putting theory into practice. The textbook/lectures already covered Gathering Information, "First Cut"s, and Revision, which are simple to grasp, but the Projects give a sense of what can get done in a given amount of time, how easy/difficult it is to actually apply those steps to a real problem, and (especially) what setbacks can occur in the process and what the end result (not just the prototype but the written work too) will look like.
• i learned the process of brainstorming, design and actually coming thru with making and presenting the product.
• design process

12. What elements of the engineering design process did you find the most helpful?
• 3-6-5
• Identify and evaluate possible design strategies
• How to work with engineering paper, different styles of brainstorming, as well as learning all about all the documentation.
• mind mapping
• gathering information, building a prototype, and documenting
• The 3-6-5 brainstorming, and the engineers Log.
• 3-6-5
• This project really gave me an example of creative problem solving. It was very refreshing,
• Making a survey so that we could figure out what the consumer needs the most. Once you know what's most important you can focus all of energy in that direction.
• mind mapping and the 3-6-5
• the planning, and the testing phase
• Documentation- it made it much easier to recall what ideas had been discussed, who was responsible for what, etc. Testing- this can be very inconvenient and time-consuming (people are disinclined to perform a step- properly- that can send them back to the drawing board), but I wish we had done more of this since that is what gives the results
real value. Testing-revision cycles seem, to me, to be the best way to get a real life sense of what engineering development is like.

- customer needs
- mind mapping

13. What elements of the engineering design process did you find least helpful?

- None
- Make "first cut" at the design
- The part about creating customer surveys, I thought that part is usually done by a customer relations person not the engineer.
- 3/6/05
- had trouble defining the overall objectives at the beginning
- The Mind map.
- mind mapping
- There were times when I felt the design process could be very fast paced and intuitive, but we were artificially slowed down for the sake of making a mind map or some other chart or list. I think there should be a general principle without specific requirements to complete the design process.
- I would have to say the grading rubric was the least helpful because we paid the least attention to it, it still did its job and helped us figure out what was most important but it seemed already implied to all of us what was most important.
- none
- documentation while useful does seem a bit cumbersome
- Documentation- I am a big fan of documentation, but if you lose a step or aren't involved in a particular step, and no documentation was written for it, it makes later steps hard to account for. In practice, documentation is very likely to fall apart if it isn't recorded at every stage; you can't just rely on one group member to record all of it- they may not be involved in every aspect of every step.
- mind map
- none
### Prototyping Supplies

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**Figure 8: Prototype Kit Supply Costs (Note: Institutions with price agreements can get many of these items cheaper than list price)**