Observations from a Two-Semester Design and Build Project

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Abstract

The design-and-build experience is a critical component of engineering education. At Francis Marion University's Industrial Engineering program, a two-semester design-and-build project was implemented. In the first semester, student teams (assigned randomly) designed vacuum forming machines using engineering requirements provided to them. In the subsequent semester, students teams were shuffled and designs (from the previous semester) were assigned to these teams for them to execute and build. The assignment of designs was performed such that all teams worked on an unfamiliar design. This simulated a real-world scenario where students worked in teams where they had no influence on team formation, and where students had to execute partially complete projects that were unfamiliar to them. The students were surveyed at the beginning and end of the second semester. Survey results indicate that, from a self-efficacy perspective: students communication skills improved; students soft skills remained unchanged; students preferred a two-semester project (as opposed to a one-semester project); students teamwork skills improved; and students felt that the two-semester project prepared them for the technical skills required in the real-world.

Keywords

Project-based learning; design-and-build; two semester project

Frame of Reference

Francis Marion University (FMU) is classified as a public, primarily undergraduate, "4-year or above"[1] university with approximately 4000 students enrolled. It has a "balanced arts and sciences/professions", with "some graduate coexistence"[1]. FMU is located in Florence, South Carolina, and most FMU students are SC residents and many are local to the region. This region (Interstate 95, Pee Dee region) of South Carolina is under-developed despite the strong presence of the manufacturing industry (413 businesses and 9398 employees[2]), and despite major transportation routes that pass through the area. A Human Needs Assessment found that regional universities, like FMU, need to develop programs that serve the local industry needs. Based on these needs, a Bachelor's of Science degree in Industrial Engineering (IE) program was started at FMU in 2014.

As of August 2018, the FMU-IE program has approximately 60 students, and has graduated three cohorts of students. Of the eleven graduates, ten were employed by regional engineering firms (at the time of graduation), and one student enrolled in graduate school. This shows the need for locally bred engineers who are fluent with engineering design and manufacturing. To meet this need a two-semester design and build project was implemented across the spring semester and fall semester of 2017.

Value of the Project-Based Design and Build Experience

Many researchers have investigated the effectiveness of Project-Based Learning (PBL) experiences. Findings from these efforts show that PBL supports the constructivist approach to teaching, and allows students to develop communication and leadership skills[3–7]. This is especially important in an engineering setting where designers need to communicate design intent to manufacturers and understand manufacturing capabilities. The motivation for the two-semester design and build project stems from the above-mentioned facts, and from the fact that a design-based PBL has positive effects on retention and student learning[8].

Implementation of the Two-Semester Design and Build Project

The FMU-IE program's curriculum is designed to educate students in three areas of industrial engineering– manufacturing, operations research, and human factors and ergonomics, and the curriculum uses the engineering design process as a framework. The curriculum introduces students to engineering design in their first year through two courses – Engineering Graphics and Introduction to Industrial Engineering. In the spring semester of the sophomore year, students take a course on Materials Engineering, and Manufacturing Processes immediately follows this in the fall semester of the junior year – where Design for X[9] is emphasized. In the final semester, the capstone Senior Design course is structured such that students use the engineering design process to implement their industrial engineering skills and solve a real-world industrial problem. While design is integrated throughout the curriculum, the key cornerstone courses (from a design-and-build standpoint) are Materials Engineering and Manufacturing Processes. The focus of this research is on a project implemented across these two courses.

It is critical for industrial engineering students to understand the engineering design process[10], design for manufacturing[9], and the need for designers to communicate with manufacturers. The design-and-build project was intended to give the students project-based learning experience in these matters.

Details of the Courses Involved

Materials Engineering:

As mentioned previously, this course is offered every spring and is designed for students in their sophomore year. The course description is as follows:

> *This course is designed to introduce students to the structures and properties of metals, ceramics, polymers, and composites. In addition, students will gain an understanding of the processing and design limitations of these materials, as well as being introduced to new classes of materials being developed to meet the ever-expanding range of material requirements. Use of materials in manufacturing in emphasized.*

The course objectives are:

By successfully completing this course, the students will:

- *Gain an understanding of the structure of (commonly used engineering) materials and how this contributes to material behavior.*

- *Gain an understanding of how materials behave during phase changes and the effects of this on manufactured products.*
- *Be able to identify and predict the effects that various manufacturing processes have on materials.*

Although engineering design is not explicitly mentioned in either the course description or the course objectives, it forms the framework for course instruction. Two class sessions are dedicated to educating the students on the engineering design process[10], with explicit directions for students to use this process during the course project.

Manufacturing Processes:

This course is offered every fall semester, has a lab component, and has Materials Engineering as a prerequisite. It is typical that all students who successfully completed Materials Engineering in a given spring semester, will take Manufacturing Processes in the subsequent fall semester. The course description is as follows:

> *This course will give students an overview of manufacturing processes primarily for metals and alloys, focusing on fabrication and joining processes. Emphasis will be placed on process capabilities and limitations, with calculation of process parameters for select processes. Also includes topics in additive manufacturing, heat treatment, product design and process planning, design-for-manufacture/assembly, numerical control, and inspection. The laboratory experience will provide manual and computer-aided process techniques, including assembly, machining, casting, welding, sheet metal forming, powder metallurgy, and inspection.*

The course objectives are:

By successfully completing this course, the students will:

- *Have a basic understanding of the fundamental processes used for manufacturing*
- *Have an understanding of engineering criteria that influence process selection to produce parts and products*
- *Understand the role of economics in the design and manufacture of parts*
- *Be exposed to emerging, state-of-the-art manufacturing processes*

Engineering design is taught during the first two weeks of the course, with a special emphasis on the need to tie product design closer to manufacturing processes. In the lab component of the course, students gain hands-on experience with activities such as tensile testing, hardness testing, casting, injection molding, and additive manufacturing. The lab hours are also used by students to work on their final projects. The next sections detail the final projects for Materials Engineering and Manufacturing Processes.

Project Details

A two semester design-and-build project was implemented across the Materials Engineering course (Spring 2017) and subsequent Manufacturing Processes course (Fall 2017). Thirteen students enrolled and completed Materials Engineering, and twelve of these thirteen enrolled and completed Manufacturing Processes.

In Spring 2017 (Phase 1), the thirteen students were divided randomly into three teams of three and one team of four students. Each team was tasked with the same project – to design a vacuum forming machine (details to follow). A Spring 2017 project deliverable was a final report. This report would become the start point for the Fall 2018 project.

In Fall 2018 (Phase 2), the twelve enrolled students were divided into four teams of three in a manner that ensured all team members were different (as compared to Spring 2017 teams). The four final project reports from Spring 2017 were distributed amongst the four teams in a manner that ensured all students were working on a project that they hadn't worked on previously.

Please visit http://people.fmarion.edu/rrenu/ASEE-SE2019/ for project descriptions and samples of student work.

The goal of implementing a two semester design-and-build project in this fashion was to mimic two real world scenarios. First, a scenario where an engineering team has been tasked with a project that has not been worked on previously, and second, a scenario where an engineering team has been tasked with continuing a project worked on by another team previously. The goal of this project was to develop students' engineering design, leadership, teamwork and communication skills. Additionally, the project was designed to emphasize the need to couple engineering design and manufacturing. Further details of both project phases is provided below.

Project Phase 1

The project was introduced to the students during the second week of the Materials Engineering. Students were provided with a project description and were explicitly informed of how their final reports would be used in the subsequent semester. Shortly after this, the instructor delivered two lectures on the engineering design process[10]. These lectures were designed to introduce students to the engineering design process, concept generation tools and concept selection tools[10].

The student teams were expected to follow the engineering design process, use the concept generation and selection tools, and design a vacuum forming machine. The requirements provided to the teams stemmed from resource availability and ease of use. The students were encouraged to interact with the professor to elicit engineering requirements beyond those provided.

Documentation expected from the teams included a technical report, engineering drawings, and instructions for use of the machines. These are reasonable expectations given that the students have experience with report writing and engineering graphics from prerequisite courses.

Project Phase 2

The project teams were formed and the project description was discussed during the first week of class. At this time, the reports from Phase 1 were provided to the student teams based on the protocol mentioned previously.

The students were encouraged to spend time studying the reports and interact with the report authors (from Phase 1) to gain a thorough understanding of design elements and design intent. The Phase 2 teams were also encouraged to interact with the instructor to elicit any further requirements. The Phase two teams were allowed to make rational design modifications (and not change the design entirely, unless absolutely required.) These teams had to provide a technical report detailing the work they performed and the rationale, a bill-of-materials used, engineering drawings, and technical instructions for using the machines they built.

Surveys Conducted

To study the effect of this project on teamwork, communication, and leadership development, two surveys were conducted – at the beginning and end of project Phase 2. Sample questions and responses from the structured surveys are provided in Table 1.

Survey Findings

All students liked working in groups at the beginning of, and at the end of Fall. This shows that the two-semester project didn't affect students' perception of their affinity for working in group projects. In fact, responses show that students learned how to manage disagreements (stemming from design ideation) and make positive strides towards addressing the project goals. This indicated that teamwork skills improved as a result of this two-semester project.

It was found that communicating within different teams and communicating with other teams helped students hone their oral communication skills. As expected, multiple in-class presentation requirements also helped improve students' oral communication.

During Phase 1, students were informed that their reports would be handed off to another team during the subsequent semester. Based on student responses to the survey, it seems as though teams were mindful of how their written reports will be interpreted. This positively affected their writing skills. Also, communicating ideas across multiple teams helped students improve their writing.

While not all students recognized the importance of communicating with the Phase 1 design team, all teams modified previous designs. This, in addition to the fact that many students noticed that understanding previous team's design intent was tough, reinforces the need to encourage students to increase communication.

Students viewed the two-semester project as a single entity with two phases, and not two separate projects. Related to this, students liked the extended amount of time they were given to work on the project. They also felt a sense of fulfillment when they realized a design during Phase 2.

Students disliked the amount of time between the two phases (Phase 1 and Phase 2 were separated by a three month summer semester). This discontinuity lead to students having to spend the first few weeks of Phase 2 acclimating themselves to the project again. Students also reported that they would have preferred to work with the same team members in both phases. Additionally, some students reported that they inherited "bad" designs which set them back during Phase 2. However, most students preferred the two-semester project over a more traditional one-semester project.

Table 1: Sample Survey Questions and Responses

What caused a change, if any, in your oral communication skills in Spring 2017?
Grouping together as well as speaking in a non-biased opinion
The experience of having to put thoughts and ideas into words in order to allow others to understand them greatly strengthened my oral communication skills.
In class presentations improved my oral speaking skills.

What caused disagreement, if any, among your Spring 2017 team members?
The actual design of the machine and what were the best ways for it to function correctly
Creative differences which were settled civilly to avoid major group disputes.
Multiple ideas conflicting together on ways to execute certain procedures or design concepts.
Idea generation caused disagreement.
Honestly, there wasn't much

What caused a change, if any, in your written communication skills in Spring 2017?
Just as with the oral communication skills, having to explain things in text rather than orally has always been more of a challenge. Explaining things thoroughly in text causes ideas to become more drawn out which still leads to issues. However, having to practice this has helped them improve, even if only minutely.
Showing me ways to use more technical writing rather than casual conversation when writing reports.
Having to write the design for the first part of the project made me think deeply about wording and interpretations of our instructions.

What were some of the challenges in taking forward another team's design?
Determining whether the design would work based on the new groups experience and opinion.
Not knowing what their original vision was for the design. We had their reports, however we did not know their thoughts and what they were thinking of heading towards as we encountered design issues.
Understanding why they chose the certain materials/functions that they did
Being able to consider safety and functionality aspects without abandoning the design completely
We did not always know what they were thinking of when certain decision was made. Unclear reports.
Understanding some of their design choices

What aspects of the two-semester project do you like?
Being able to spend more time both designing and building.
Seeing the project be completed from design to actually building it.
There was more time to work on the project and improve upon very beginner ideas from just the materials standpoint
I liked the fact we received a different groups design and then we had to manufacture it. This gave us a good idea of how the design phase is different than the manufacture phase. It learned us how to design better for manufacturing.
Having the opportunity to work with more people

What aspects of the two-semester project do you dislike?
I enjoyed both of my teams, however a single team throughout the projects would have been nice.
The extended time allowed for information to be forgotten.
Working on a different design than we previously had. I would have enjoyed working on my own design, however it makes sense to switch up what the groups and designs were.

What aspects of the two-semester project do you dislike?
I disliked the discontinuity between groups. I did not like receiving a different team's project.
Having to troubleshoot and manufacture someone else's design

Conclusions and Future Work

By implementing the two semester design-and-build project, it was observed that students' communication skills, both oral and written, improved. Students gained first-hand experience on a project leading to an understanding for the need for communication between design and manufacturing. Students reported minimal misunderstandings in their respective teams, which might be an indication of effective leadership. From an instructor's standpoint, the following points are important to note:

1. Program size and annual course offerings ensure students travel through engineering courses as cohorts – this enables multi-semester projects to be offered and students can interact with previous teams.
2. Communication with Phase 1 teams is beneficial and must be enabled. Program size and frequency of course offerings will dictate mode(s) of communication.
3. Safety and use of Personal Protective Equipment must be emphasized, and (in addition to faculty/staff supervision) students must self-regulate.

For future work, similar projects can be implemented and more surveys conducted. Additionally, a similarly structured project should be conducted at (larger) institutions where access to prior teams is limited and/or different.

References

1. Lookup CC| I. Carnegie Classifications.
2. South Carolina Chamber of Commerce. *2018 Workforce & Jobs Report*.; 2018.
3. Thomas JW. *A Review of Research on Project-Based Learning*. San Rafael, California; 2000. doi:10.1007/s11528-009-0302-x.
4. Ross SM, Wang LW, Alberg M, Sanders WL, Wright SP, Stringfield S. Fourth-Year Achievement Results on the Tennessee Value-Added Assessment System for Restructuring Schools in Memphis. 2001.
5. Stepien W, Gallagher S. Problem-based learning: As authentic as it gets. *Educational leadership*. 1993;50:25.
6. Blumenfeld PC, Krajcik JS, Marx RW, Soloway E. Lessons learned: How collaboration helped middle grade science teachers learn project-based instruction. *The Elementary School Journal*. 1994;94(5):539-551.
7. Frank M, Lavy I, Elata D. Implementing the project-based learning approach in an academic engineering course. *International Journal of Technology and Design Education*. 2003;13(3):273-288. doi:10.1023/A:1026192113732.
8. Dym CL, Agogino AM, Frey DD, Leifer LJ, Eris O. Engineering Design Thinking , Teaching , and Learning. *Journal of Engineering Education*. 2005;94(1):103-120.
9. Boothroyd G, Leo A. Design for Assembly and Disassembly. *CIRP Annals-Manufacturing Technology*. 1992;41(2):625-636.
10. Pahl G, Beitz W, Wallace K, Blessing L. *Engineering Design: A Systematic Approach*. 3rd ed. London: Springer-Verlag London Limited; 2007.

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