

Formulation of Capstone Design Projects for Experiential Learning

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This paper outlines a general method that is utilized in the Department of Mechanical Science and Engineering (MechSE) at the University of Illinois to formulate capstone design projects that promote experiential learning in accordance with Kolb's experiential learning theory. Namely, capstone projects should have a sponsor who will provide the students with a concrete experience through a real design project that they care about, constructive feedback on their designs, realistic design constraints, and a reasonable scope for the duration of the project, team size, and constituents. In addition, projects should have design reviews whereby the students can receive feedback on their designs to enable reflective observation and abstract conceptualization. The deliverables should include reports and presentations to provide venues for constructive feedback, and prototypes and test data to facilitate active experimentation. It is necessary to have proper facilities and resources to support the projects if the students are to build and test their designs. This paper further outlines how these methods are used by the MechSE Department in formulating engineering competition, industrial, humanitarian, and entrepreneurial projects for experiential learning.

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Introduction

Experiential learning has been found by researchers, such as Chan¹, to be an effective learning method. Kolb² developed a four stage learning cycle theory used to characterize experiential learning. It consists of 1) concrete experience 2) reflective observation 3) abstract conceptualization and 4) active experimentation. This paper outlines methods for formulation of capstone design projects that utilize Kolb's experiential learning cycle and implementation of these methods at the University of Illinois Department of Mechanical Science and Engineering. The University of Illinois Department of Mechanical Science and Engineering (MechSE) engages its students in approximately 50 different capstone projects per year. The capstone design projects can be classified into four categories: engineering competitions, industrial projects, humanitarian projects, and entrepreneurial projects. All of these projects have a faculty advisor to help guide the students in the experiential learning process. Faculty are assigned as advisors for two projects every three semesters as part of their regular teaching assignment. In addition, one teaching assistant is assigned to every eight teams to further assist in the learning process and especially focusing on the written and verbal communication skills. All of these projects involve experiential learning that follows Kolb's model. All of these projects involve the concrete experience of designing something real, and in most cases also building and testing the design. In the MechSE capstone design course (ME 470) the students are required to undergo design reviews that stimulate

reflective observation where they receive feedback from the faculty advisor and industry representatives on their designs. The faculty and reviewers identify design problems or new opportunities that may be apparent to the trained eye. This spurs the students to the abstract conceptualization stage where they modify or develop new designs or refinements of their design in view of their reflections. The students then have the opportunity to realize their designs by building them and then testing them in the active experimentation phase. Through experimentation the students learn that parts may not go together as they planned, they may fail, overheat, or fail to meet the design constraints. This leads to a new concrete experience where they need to overcome the problems with the design to meet the constraints, and so Kolb's experiential learning cycle repeats.

General Project Formulation

Project formulation is important in making a successful capstone design project that involves experiential learning. The following are general formulation guidelines utilized at the U of I MechSE Department:

Project Sponsor

One of the most important aspects of a successful project is identifying an effective project sponsor. The project sponsor should care about the project and hence be motivated to help define the design problem as well as provide regular feedback. The sponsor is the one providing the concrete experience by posing a real design problem and providing funding to solve it. An

effective sponsor will spur the students to engage in reflective observation as they provide constructive feedback on their designs.

Project Design Constraints

Real design projects should have multiple realistic constraints. In fact, the ABET Engineering Accreditation Commission (EAC) indicates, under General Criteria 5. Curriculum, that “Students must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.”³ The constraints may include, but not limited to, the following constraints outlined in ABET General Criterion 3. Student Outcomes: economic, environmental, sustainability, manufacturability, ethical, health and safety, social, and political.³

Scope

The scope of the projects must be proper for the length of the project, number of students involved, and disciplines involved. If the project is too simple the students will not be challenged, and hence will not learn as much. If the project is too complicated or long, or the project is not suitable for the curricula of the team constituents, students will become frustrated and may not produce a design that satisfies all constraints by the end of the capstone project. Longer term projects can be beneficial as it can allow for multiple iterations of the design to occur.

Deliverables

The deliverables should also be clear in order to have a successful result. The deliverables should include reports and presentations throughout the project which serve as opportunities to review the students work. In addition, a working prototype of the proposed design is desirable, because it provides the opportunity for students to perform active experimentation in constructing and testing the design to see if it satisfies the design constraints. For this reason, the requirement of test results as a deliverable is also desirable. Depending on the timescale of the project, multiple iterations may be possible before the final design and prototype is constructed and tested.

Design Reviews

In order for students to have reflective observation in their experiential learning cycle they must have some feedback. Design reviews by the companies, faculty, and TA's can provide this feedback not only on the design, but also the students written and oral

communication skills. The students' reflective observations that result from the reviews lead them to refine their designs and communication skills.

Facilities and Resources

If students are expected to design, build, and test their designs there should be sufficient facilities and resources to support these activities.

Track-Specific Implementation

Engineering Competitions

The following engineering competitions are utilized in the U of I MechSE senior design program:

- Formula SAE
- Formula Electric SAE
- Baja SAE
- Shell Eco-Marathon Prototype
- Shell Eco-Marathon Urban concept
- Parker Hannifin Chainless Challenge

These sponsors are keenly interested in providing students with a real world experience. Engineering competitions can be easier to formulate for experiential learning than other types of senior design projects as the project design constraints (rules), scope, and final deliverables are already set. Moreover, all of these projects involve the concrete experience of designing, building, and testing (racing) a real vehicle. The scopes of these projects typically involve a one year design and build cycle. The students work on these projects at the in an independent study (ME 497) or interdisciplinary course (ENG 491) one semester and the capstone design course (ME 470) in the following semester in order to accommodate the one year design, build, and test cycle. However, the sponsor of the competition may or may not provide feedback through regular design reviews, depending on the competition, which is important for reflective observation, and consequently abstract conceptualization to occur. In order to tackle this issue the U of I MechSE Department requires regular internal design reports and reviews for all of these competitions by at least the faculty advisor. The SAE competitions also have experienced alumni providing feedback on the reviews. With the exception of the Parker Hannifin Chainless Challenge, all of these competitions involve multidisciplinary teams, which add to the realistic concrete experience. Students in disciplines other than mechanical engineering and engineering mechanics simply register for capstone design courses in their respective departments.

The students engaged in these competitions at the University of Illinois utilize both MechSE Departmental and/or college facilities to aid in the design, construction, and testing of the vehicles. The college facilities include a machine shop, tools, space for the

students to work, and professional machinists overseeing the facilities. The MechSE departmental facilities and resources include CNC lathes, CNC mills, plastic selective laser sintering machines, stereolithography machines, 3dimensional printers, CNC 5 axis milling machine, CNC water jet cutter, laser cutters, a bench to work on, tools, and skilled machinists to consult with. The department also has millions of dollars of test, measurement, and data acquisition equipment including engine dynamometers for use in MechSE capstone design projects. The funding for these competitions comes from department, college, and industrial sponsors unrelated to the competition sponsors with the exception of the Parker Hannifin Chainless Challenge. Parker Hannifin provides the majority of the project funding.

Industry Projects

The majority of the capstone design projects in the MechSE Department are industrial sponsored projects. The MechSE Department's Senior Design Project Coordinator (present author) utilizes alumni and industry contacts to identify potential sponsors. Typically, a visit to the sponsor is necessary to properly formulate the project description. He works with the companies to draft project description outlining the design project with major project constraints, scope, and deliverables defined. The scope is defined to take teams of 3 to 4 students, a typical team size, one semester to complete. In Fall 2012 MechSE piloted one two-semester capstone design project using the design competition model of enrolling in capstone design (ME 470) in one semester and independent study (ME 497) in the other semester. The team size was also doubled to 8 students. As a result, the scope was approximately four times that of a usual project. The sponsor provided double the normal donation and the students were given double the budget. This allowed the students to make multiple design iterations, which allowed multiple Kolb experiential learning cycles to occur during the duration of the project. The end result was a well thought out design and a working prototype. Furthermore, the team won a MechSE outstanding achievement award. In the Fall 2013 semester MechSE piloted two two-semester senior design projects. Both projects are progressing well with promising designs and proof of concept prototypes. With another semester of design iterations and testing they will likely be on par with the previous two semester project.

A committee reviews all of the projects to ensure sufficient design constraints, content, scope, and deliverables. It is important to not allow projects that only involve analysis or testing. While these projects might reflect the needs of industry, they would not involve design that would be conducive to experiential

learning with concrete experience, reflective observation, abstract conceptualization, and active experimentation. One should not give up entirely on an apparent analysis or testing project. Instead, this is an opportunity to redefine the project as a design project or a design of a test stand, respectively. However, from experience, if the sponsor does not appear to be keen on this redefinition of the scope it is better to pass on the project. The student teams and faculty view the project descriptions and list their top 5 projects out of 24. The student teams and faculty are then matched based on their interests. In this way the students and faculty are interested in the projects. The project descriptions do not fully define the problem. This is left up to the students to define after meeting with the company, which adds to the student learning process.

The deliverables for industry projects are a preliminary design report and presentation where the students fully define the design problem and propose to the company their plan of attack to solve the problem, a mid-semester status report and presentation, and a final report and presentation. The faculty, TA's, and industry sponsors provide feedback on each of the reports. In addition, MechSE strongly encourages projects to involve building and testing at least one prototype. This aids in the experiential learning process as they are able to conduct active experimentation. The students typically deliver the prototype and the test data to the sponsor at the completion of the project.

The Industry Projects utilize the same facilities and tools as the competitions with the exception of personal access to a machine shop. Instead, when traditional machining is required, these students are able to submit their drawings to skilled machinists who operate the machines. This is necessary due to space constraints. The industrial sponsors provide \$4,000 to cover the cost of the course. The students are allocated a budget of \$1,000 from these funds for material expenses involved in building and testing prototypes and travel.

Humanitarian Projects

The MechSE Department also takes on humanitarian projects. These projects are sponsored by industry, but are not technically involved in the projects. Instead, a technical contact is identified to serve as in the same capacity as an industrial sponsor. These contacts may be non for profit organizations, non- governmental organizations (NGO), or surgeons in hospitals. These contacts and projects have been identified from student groups such as the local chapter of Engineers Without Borders (EWB), and from alumni and faculty. Prior to this practice we had instances where the student leaders in EWB act as the sponsor. This did not yield an effective design as there was not the same level of accountability and oversight. Presently, the students

have a real professional to please with their design and hence a concrete experience. In one recent instance, a senior design team designed, built, and tested treadle pump for irrigation purposes in rural Cambodia using locally available materials. Shell Oil Company provided the funds, but a NGO acted as the technical contact⁴. The senior design project coordinator worked with the technical contact to identify the design constraints, scope, and deliverables. The experiential learning and active experimentation in this project was taken to a higher level as the MechSE Department funded the team's travel to Cambodia to test their design in the field. The design reviews and facilities utilized for the humanitarian projects are the same as outlined for the Industrial projects.

Entrepreneurial Projects

The MechSE Department is actively encouraging its students to become entrepreneurs. MechSE students are given lectures to foster entrepreneurship in design courses such as Computer Aided Design (ME 170), Design for Manufacturability (ME 350), and Engineering Design Principals (TAM 302). In ME 350 and TAM 302 MechSE juniors design and build a product. In the Spring semester of the junior year the students are invited to submit proposals for their own entrepreneurial capstone design project. At the end of the spring semester the competing students present their entrepreneurial design project ideas to a committee of faculty with industrial and entrepreneurial experience. The top teams have their own capstone design project in the following Fall semester. In some respects the students act as the sponsor in this arrangement. However, the committee also acts as a sponsor by ensuring that the design constraints, scope, and deliverables are at least to the same level as the industry sponsored projects. The committee and a selected faculty advisor provide feedback on their design. Designing, building, and testing prototype(s) is also a requirement for these entrepreneurial projects. In addition, these teams must present a business model for their design. The students undergo the same design reviews as the industrial projects with the addition that the students present their work at the completion of the capstone design phase to the review committee. If the committee determines that they have a sound design and business plan they are given funds to help them start a business. Two startup companies have formed from these entrepreneurial projects in the last three years. The facilities for these projects are the same as for the Industry Projects, but they are given an increased budget of \$5,000.

Additional Lessons Learned

Having a handful of faculty members committed to providing an equivalent course structure and review process is key to consistent experiential learning when there are multiple capstone design options. Also, it is observed that longer duration design projects, such as two semester projects, often result in better design outcomes and experiential learning in capstone projects because students are able to have multiple Kolb² cycles.

Conclusion

In conclusion, experiential learning as outlined by Kolb can be effectively incorporated in the capstone design experience through careful project formulation. Capstone projects should have a sponsor who will provide the students with a concrete experience through a real design project that they care about, constructive feedback on their designs, realistic design constraints, and a reasonable scope for the duration of the project, team size, and constituents. The deliverables should include prototypes and test data to facilitate active experimentation as well as reports and presentations to provide venues for design reviews whereby the students can receive constructive feedback on their designs to enable reflective observation and abstract conceptualization. It is necessary to have proper facilities and resources to support the projects if the students are to build and test their designs. The U of I MechSE capstone design program has implemented these methods in formulating engineering competition, industrial, humanitarian, and entrepreneurial projects for experiential learning. Finally, it is important to have faculty members committed to maintaining an equivalent course structure and review process in order to provide consistent experiential learning when there are multiple capstone design options available.

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