Linking Student-Initiated Projects to Engineering Design Education

Sven G. Bilén, Robert N. Pangborn, and Hanna Lee

College of Engineering
The Pennsylvania State University
University Park, PA 16802

1. Introduction

The engineering design process is paramount to the practice of engineering; hence, engineering programs have made increasing commitments to teaching design as part of design courses, particularly capstone design classes. In the engineering colleges of most universities, however, there exists a largely untapped resource for providing formalized design experience, that being the student-initiated design project. These design projects, oftentimes highly competitive in nature, are initiated and managed by student chapters of engineering societies as well as teams of students that form temporarily to meet a certain goal. Examples of such team projects include Solar Car, SAE Formula One Racing, and Concrete Canoe, to name but a few. These design projects can and do equip students with many of the abilities that industry desires in the new engineering graduate, such as ability to address a customer's real needs, effective time management, experience with integrated product development/concurrent engineering, effective communication skills, thorough understanding of current design tools, and sense of the total business equation. These projects also provide the student with "hands-on" experience in "real-world" engineering problems and are often very interdisciplinary in nature. Unfortunately, because of their extra-curricular nature, it is often difficult to link them formally to educational goals or integrate them into the formal engineering design curricula.

The ABET definition of engineering design is "the process of devising a system, component, or process to meet desired needs."[1] The design-related requirements that ABET places on U.S. engineering programs for accreditation state that a curriculum must include most of the following features:

- development of student creativity;
- use of open-ended problems;
- development and use of modern design theory and methodology;
- formulation of design problem statements and specifications;
- consideration of alternative solutions;
- feasibility considerations;

- production processes;
- concurrent engineering design; and
- detailed system descriptions.

When providing design projects, ABET also indicates that the design experience should:

- include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact;
- be a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills;
- be taught in section sizes that are small enough to allow interaction between teacher and student;
- be an experience that must grow with the student's development; and
- focus the student's attention on professional practice and be drawn from past course work.

This paper describes the student-initiated design project and what kinds of steps can be taken to formalize the educational, rather than just the experiential, aspects of the design experience. The purpose of this paper is not to provide an exhaustive "how-to", but rather to provide some examples of the kinds of things that can be done as well as some of the anticipated educational benefits and problems. To guide our discussion, we have presented above the ABET requirements for design in the curriculum and the attributes of meaningful design experiences. We will first take a look at the points in the curriculum where design has traditionally been found. We follow by defining the student-initiated design project and present some observations of data collected from student organizations in the College of Engineering at The Pennsylvania State University. We then discuss the methods that can be employed to formalize the educational experience.

2. Engineering Design in the Curriculum

Presently, many engineering programs have two courses containing the primary engineering design content, these being a first or sophomore year introductory engineering design course and a senior capstone design class. This is the case at Penn State, and a recent review article of design programs[2] described similar situations at MIT, University of Texas, and the U.S. Air Force Academy. As part of the capstone design curriculum, "industry-sponsored" and "professor-driven" design projects are now fairly commonplace. Many engineering programs (including Penn State's) provide capstone design experiences via industry-sponsored design projects.[3] These projects are excellent methods for providing meaningful "real world" design experiences, although they have their own set of difficulties. Professor-driven projects in the capstone design course are also valuable in that the design experience can be tailored to course content and desired educational outcomes.[4] Reverse engineering techniques in teaching design have also been employed with success in capstone and introductory design classes.[5]

Having a first-year or introductory design experience and then a capstone senior course in design raises several obvious issues.[6] We may establish competencies that are learned in the first-year design course as desirable and known for entry into the senior course. However, as two or more years go by, retention of knowledge learned may not be high. As a result, capstone design

courses are often taught as standalone pre-professional courses that owe little if anything to the entry-level course. If even a few students who were interested in design took one or two courses or were involved in student-initiated projects in their second and third years, one can speculate that the availability of these students would make a marked impact on the capstone courses by providing a natural cohort of team leaders. One possibility for the middle years is "harnessing" the many student-initiated design projects,[7] which could benefit significantly by formalizing the relationship between the student project and the design education process.

3. Student-Initiated Projects

"Student-initiated" projects, in their purest form, are projects that are initially pursued by a student or group of students, often related to their specific interests. Frequently, members of the student branch of professional engineering organizations such as IEEE, AIAA, ASME, etc., will pursue a competitive project sponsored by the national organization. Other possibilities include projects sponsored by government agencies such as NASA, local community agencies, or corporate sponsors. The projects are often competitive in nature, although competition is by no means a requirement.

As mentioned above, in the design curriculum, industry-sponsored and professor-driven design projects have become fairly commonplace, particularly in capstone design courses. Professor-driven projects are also valuable in that the design experience can be tailored greatly to course content and desired educational outcomes. Hence, as they are already integral to a given design course, these two types of projects (or three if you allow students to define their own design project,[4] e.g., in a capstone design course) should ideally already address ABET design criteria successfully—or at least make an attempt to do so. On the other hand, the student-initiated design project may benefit greatly by formalizing the relationship between the student-run project and the educational process through methods such as establishing a design course for the entire project or providing independent study opportunities focused on measurable criteria, as well as incorporating smaller pieces into established design courses.

An important feature of student team projects is that they are generally vertically integrated, that is, they involve students at all stages of education, from first year to graduate students. This type of vertical integration, while occasionally attempted in established design courses (e.g., see Clayton[8] and Tao[5]), is generally quite difficult to get to work well in practice. Vertical integration provides several natural benefits, however. One of the benefits is that students learn from other students. The more advanced students often are the leaders and mentors of the students at earlier stages of engineering study; as students advance, they subsequently take on the role of mentor to the "new recruits." Hence, the more senior students obtain experience in realistic management situations and the understudies benefit from the mentoring as well as gain a preview of what is to come in academics and careers.[5] This is very similar to what the students will see in engineering practice as they move from subordinate to supervisory roles.

The College of Engineering at Penn State has seen a surge in interest in student projects and a corresponding increase in requests for resources to support these projects. Since the projects provide an excellent method for enhancing the design and professional education of

students, we are seeking the best methods to support them and finding ways to integrate better the experiences they provide into the engineering curriculum where appropriate. Our effort embraces the major on-going initiatives and also includes short-term team projects and research initiatives. Ideally, any effort should cover both individual and collective activities.

Our College annually collects data on what types of activities our students participate in while they are students, as well as what job functions our graduates do with respect to length of time since graduation.[9] The data allows us to perform a longitudinal analysis to look for short-term and long-term trends. Of particular relevance to student projects are two pieces of interesting data: 1) although female participation in student societies is much greater than that of males, males participate at higher rates in student competitions; and 2) the frequency with which graduates are performing job functions related to design has significantly increased in the past decade.

Representatives from industry have become particularly cognizant of ABET requirements and have expressed concern that the student projects they are funding are "open loop" from the educational process. For example, some industry representatives have asked how student projects they are funding were meeting ABET2000 criteria for design and indicated that the projects should be better linked to the educational process in order to meet these goals. Hence, having a policy and mechanisms in place showing that the educational aspects of projects are being addressed may lead to more project support by corporate sponsors, particularly for those organizations that consider themselves supporters of the educational mission of universities.

4. Surveys of Student Perception and Issues with Projects

An assessment of the current situation with respect to student-initiated projects in Penn State's College of Engineering was made via a survey that was sent out to leaders of the approximately fifty student engineering organizations (50% of surveys were returned). General observations of survey results are presented below:

- About 20% of the organizations were involved with or sponsored some type of project work.
- New organizations and project teams have difficulty knowing how to obtain resources and work within the college. Methods for obtaining space and funds are not always clear.
- There is not enough publicity about projects across the College. For example, an aerospace engineering student might not be aware of projects offered in electrical engineering that match his or her interests. Similarly, projects sponsored by one organization might be of interest to members of another organization, but organizations are not sure how to solicit the assistance.
- Many students indicate that they find it difficult to work on a project for which they are not receiving academic credit for their work because their schedules are already full with their courses.
- There is still very limited "subcontracting" of projects to the capstone design classes.
- Most of the project work is confined to and focused on undergraduates, but there is some interest in projects at the graduate student level as well.

- Projects not linked to an organization, or that lack strong faculty backing, have much more difficultly obtaining resources than those that are well supported or "connected."
- Some students indicated a desire to receive credit for "volunteer" activities like working with Habitat for Humanity.
- Most groups felt that there are enough project opportunities, although there are some who did not. It is not clear if this is simply due to lack of publicity.
- Students do not always understand the methods for obtaining academic credit for project work.

5. Methods for Linking Projects to Design Education

For the maximum impact of any linkage, it is important to find the right fit to the project and to identify those projects that will benefit significantly from the linkage. For example, establishing a design course to support a particular project is best suited to a case where the project has little established history, has lapsed for several semesters, or has difficulty progressing. Some well-established teams that continue in perpetuity may simply perform design iterations year to year, and in this case may benefit from more limited or compartmentalized methods such as "subcontracting."

One of the concerns when formalizing the educational aspects of the student-initiated design project is the issue of student ownership. It is vitally important that students feel that they retain ownership of their project.[10] The instructor or advisor must be careful not to take over the direction of the project; rather he or she should hold to guiding the students, questioning them on project progress, and helping obtain appropriate resources. Done properly, the design experience will boost the confidence of the design team members as they see success in their portion of the project and in the overall design. The university setting is an excellent venue for students to retain control of the design. Upon graduation, an engineer may wait several years before they are able to feel the same sense of ownership and accomplishment.

These design projects also offer excellent opportunities for the development of leadership and project management skills. As Bond[11] indicates, "the 'great' new engineer is the student who has learned the required technical material plus basic interpersonal skills, the dynamics of teams, conflict resolution, project definition, communication, and meeting skills that would normally be thought of as management/leadership skills." One of the other observations is that it is important for the design project to have a strong and committed leader. Kitto[12] gives a particularly descriptive explanation of the dynamics between the leader and the subordinates: "Examining team dynamics in these projects is very interesting. Almost all student leaders go through a moderate beginning phase where patience and a small amount of direction is imposed, followed by their personal frustration and then their passage through a dictatorial stage. The team almost always rebels against the leader during that phase, only to later rally around the leader once those team dynamics are worked through and clear lines of leadership and responsibilities are established. The workload for the faculty member increases during that turbulent phase and their role is to serve as moderator and true team leader. Once the process is understood by faculty, this becomes an additional part of the process, ranking a close second to the technical issues." This is truly a development process for the project leader and team members.

In the section below, we will examine the methods for tapping into student-initiated projects at three different levels:[13]

- students in established departmental or interdepartmental design classes (*e.g.,* "capstone" design classes);
- students who can be involved via independent-study projects; and
- students who volunteer their time to the project for a variety of reasons including personal satisfaction, personal enrichment, and augmentation of engineering skills.

Established Design Courses

This linkage method works by linking students and student teams from established departmental design classes by "subcontracting" out a well defined section of design effort. Many students in team projects are simultaneously in small-group capstone design courses and/or courses with major design content (e.g., a finite element analysis course). Even if they are not, these courses are continually looking for real-world projects, and such a project may be found very exciting by many students. To give an example of such a subcontracting situation at Penn State, the Flyin' Lions—an "established" team with an ongoing long-term project for flight in NASA's Reduced Gravity Student Flight Opportunities Program—subcontracted out improving the motor control system of a astronaut exercise system to a small team in the electrical engineering capstone design class.

A department or college may also choose to set up a continuing course to offer the projects. For example, at Penn State the SPIRIT (Student Participation in Rocket Investigation Techniques) rocket project has an established course that students may take for a few credits per semester.[14] As another example, EPICS (Engineering Projects In Community Service) projects, are another venue for student design projects that focus on community service.[15,16] The program was started at Purdue and exists now at a numbers of other universities, including Penn State. At some universities, the projects have become institutionalized through the offering of a separate course; however, at Penn State most EPICS projects are offered via the capstone design course.

Independent Studies

The second category comprises students who participate in the project via independent-study efforts, which are formal arrangements set up between a faculty and the student. When initiating an independent study effort, the student and faculty advisor begin by defining set of goals that can then be used as a metric for assigning a grade. The students typically sign up for 2 to 4 credit hours, which entail 6 to 12 hours of work per week, respectively, and are required to submit a final report. A large part of their grade is based on the final report. The benefit of having students work in this manner is that the team, by way of the advisor or mentor, is more certain that needed work will get done—and be done well.

As is the case at most universities, every department in the College offers an independent studies option of which, in general, 3 credits may be used to satisfy senior-level technical electives. As an example, to initiate a independent studies course within EE, the student and the advisor fill out a form that contains the title and a brief description of the project as well as criteria to be used for assigning a grade. Explicit reference to ABET criteria, in general, is not currently

made, although such consideration certainly should be made. Hence, we are moving toward requiring a "contract" for students who wish to receive academic credit for design projects. In order to be most effective, we will also have to develop a post-project metric to evaluate how the project addressed ABET requirements.

Students are often not aware of the ABET requirements on design experiences, and as such may propose an inappropriate experience for design credit. For example, one of the comments received in the survey was to provide a mechanism for students to receive credit for volunteer weekend work for organizations such as Habitat for Humanity. Although under a different guise this might be appropriate, it is clearly not appropriate from a design perspective, unless a specific design problem is worked on in that context (and, as such might make an excellent project for EPICS). Having students fill out a contract that specifically requires them to explain how the project meets several of the ABET requirements would help them understand the educational requirements of a project and not just the quantity of work required. Such a contract should request the following information:

- Name of each student wishing to receive design credit
- Who the advisor/mentor is (faculty and/or industry contact) and their involvement level
- Objectives and short project description
- Types of reporting methods used (written reports, CAD drawings, experiments, constructed equipment or models, oral reports, etc.)
- Basis for project grade
- Whether there is an expectation to present at the Project Design Showcase, which is a college-wide exposition of project work held at the end of fall and spring semesters
- More complete description with a discussion of how the project will meet the ABET Criteria

This type of information is currently collected by some programs, e.g., The University of Wyoming's Civil and Architectural Engineering Department requires students to get approval for design projects that are awarded academic credit via a *Comprehensive Design Experience Approval Form*, which requires students specifically to think about how their proposed design experience addresses ABET design criteria. A post-project metric that would include a dossier of the work as well as an analysis of the design experience also should be collected and required for a grade. These could then be provided to the undergraduate coordinator for the program and ABET review purposes.

Another type of independent team is an E-Team, which is sponsored by the NCIIA. E-teams work on later-stage development of an idea and a plan for its commercialization. They may include engineering students as well as students from business and other majors, and each team must have a faculty advisor. E-Teams may form as part of a course or on the independent initiative of students, faculty, or other representatives of member institutions.[17]

Volunteers

Student design projects generally contain a large cast of volunteers, which are perhaps best harnessed via active involvement by the faculty advisor(s) or industry/government mentors. This group includes students who work on a project without receiving academic credit or

monetary compensation. The reasons for students joining at this level are varied and include personal satisfaction, personal educational enrichment, and augmentation of engineering skills. These students are generally highly motivated and provide continuity and the necessary expertise at critical times during a project. Considering volunteers is important because many students initially join a project either as a volunteer or perhaps by being involved through a subcontract in a capstone design class. Many students who take on independent studies, for example, do so either because they need or are encouraged to receive engineering design credit for their work.

Resources

One of the largest issues with linking student-initiated design projects to the educational process is the increase in faculty workload, hardly a trivial matter. Offering a dedicated course requires a significant time commitment and must not be entered into lightly. The ability to provide an excellent design experience to the students may be the only reward to the instructor. However, one method for an instructor to derive benefit is to only commit time and effort to projects that will also benefit the instructor's research or educational goals. More limited involvement that still provides meaningful experiences can be accomplished through identifying portions of the project that may benefit from the three-category approach outlined above.

A centralized facility to promote and manage student projects is also important, and many engineering colleges are establishing these; e.g., the Learning Factory at Penn State. A central facility can track and provide information on projects across a college. That way, for example, an aerospace engineering student would be aware of projects offered in electrical engineering that match his or her interests. This would also pertain to projects sponsored by one organization that might be of interest to members of another organization. The facility can also track and administer resources available for project work.

Administrative support of student-initiated projects is also of vital importance and without it any attempt at linkages is highly likely to fail or carry little reward. This support may take several different forms, but could include financial assistance to support the project, providing office and work space, waiving or covering fees for producing prototypes, and providing a faculty advisor a "buyout" of other teaching responsibilities to offer a design course, to name but a few.

6. Summary

Tapping into the design project resource provided by the student-initiated design project is an important method for incorporating meaningful engineering design experiences into the curriculum. Several methods for linking these projects are presented in this paper, including development of a project-specific design course, subcontracting to other design courses a portion of the design project, independent-study projects, and providing design mentoring to volunteers. Linking these design projects is only one possible method for providing meaningful design experiences, but an important method for supplementing the array of much needed design opportunities available to students.

References

1. ABET Engineering Criteria 2000, http://www.abet.org, 2000.

2. Wood, Kristin L., Daniel Jensen, Joseph Bezdek, and Kevin N. Otto, "Reverse Engineering and Redesign: Courses to Incrementally and Systematically Teach Design," *Journal of Engineering Education*, Vol. 90, No. 3, 2001, pp. 363–374.

3. Lamancusa, J. S., J. E. Jorgensen, and J. L. Zayas–Castro, "The Learning Factory—A new approach to integrating design and manufacturing into engineering curricula," *Journal of Engineering Education*, Vol. 86, No. 2, April 1997, pp. 103–112.

4. Ansell, H. G., "Professor-driven, student-driven, and client-driven design projects," 1998 ASEE/IEEE Frontiers in Education Conference, Tempe, AZ, November 5–8, 1998, pp. 149–154.

5. Tao, B. Y., "Senior/sophomore co-class instruction: Teaching interpersonal skills in engineering," *Journal of Engineering Education*, Vol. 82, No. 2, 1993, pp. 126–129.

6. Bilén, Sven G., Richard Devon, and Gül E Okudan Kremer, "Cumulative knowledge and the teaching of engineering design processes," 2002 ASEE Annual Conference, Montréal, Québec, Canada, 16–19 June 2002.

7. Bilén, S. G., "Enhancing engineering education by harnessing the student-initiated design project," ICEE 2001, Olso, Norway, 6–10 August, 2001.

8. Clayton, J., Martin, D., and S. W. Martin, "Multi-level design teams: A success story?" 30th ASEE/IEEE Frontiers in Education Conference, Kansas City, MO, 18–21 October, 2000.

9. Pangborn, R. N., "What Are Our Students (and Graduates) Doing? A Longitudinal Analysis," presentation to the Faculty Advisory Board, Penn State University April 2002.

10. Dekker, D. L., "Issues when using company sponsored design projects to provide a design experience for students," 1997 ASEE/IEEE Frontiers in Education Conference, Pittsburgh, PA, 5–8 November, 1997, pp. 304–306.

11. Bond, H. B., "Enhancing the career impact of design courses," IEEE Transactions on Education, Vol. 41, No. 4, 1998, p. 350.

12. Kitto, K. L., "Integrating concurrent engineering into the undergraduate design and research experiences," 1997 ASEE/IEEE Frontiers in Education Conference, Pittsburgh, PA, 5–8 November, 1997, pp. 955–959.

13. Bilén, S. G. and L. P. Bernal, "The Vortex Ring Transit Experiment Get Away Special Project: Using projects sponsored by student organizations to enhance engineering education," ASEE 1998 Spring Conference, North Central Section, University of Detroit Mercy, Detroit, MI, 2–4 April 1998, pp. 211–215.

14. Mitchell, J.D., T.F. Wheeler, C.L. Croskey, and D.M. Meisel, "SPIRIT: Student Projects Involving Rocket Investigation Techniques," *ESA SP–437*, September 1999.

15. Jamieson, L. H., W. C. Oakes, Edward J. Coyle, "EPICS: Documenting service-learning to Meet EC 2000," 31st ASEE/IEEE Frontiers in Education Conference, Reno, NV, 10–13 October 2001.

16. Oakes, W. C., A, Krull, E. Coyle, L. H. Jamieson, and M. King, "EPICS: Interdisciplinary service learning using engineering design projects," 30th ASEE/IEEE Frontiers in Education Conference, Kansas City, MO, 18–21 October 2000.

17. Mason, T. W., and F. C. Berry, "Assessing the outcomes of E-Teams for Engineers," NCIIA 6th Annual Meeting, 14–16 March 2002, Arlington, VA.

SVEN G. BILÉN (BS Penn State, MSE and PhD Univ. of Michigan) is an Assistant Professor of Engineering Design and Electrical Engineering at Penn State. His educational research interests include developing techniques for enhancing engineering design education, teaching technological entrepreneurship, and global product design. He acts as faculty advisor for a number of student design projects, including the Flyin' Lions and Get Away Special payloads teams. He is member of IEEE, AIAA, AGU, ASEE, URSI, and Sigma Xi.

ROBERT N. PANGBORN is Professor of Engineering Mechanics and Associate Dean for Undergraduate Studies in the College of Engineering at Penn State. He holds B.S. and B.A. degrees in Civil Engineering and Business Administration, and earned his M.S. and Ph.D. degrees in Mechanics and Materials Science at Rutgers University. He chaired the Special Committee on General Education at Penn State and has led a number of interdisciplinary initiatives focused on curricular change and integration. He teaches and conducts research in engineering mechanics and materials.

HANNA LEE is an undergraduate student at The Pennsylvania State University working towards her B.S. in Electrical Engineering with a minor in Bioengineering. Her areas of interests are in semiconductor devices and in the analysis and design of information transmission systems for communication with an emphasis in computer networking. She is also involved in the research and development of ultrasonic motors for medical applications at the university.