

AC 2001-1092: USING DESIGN AS THE BACKBONE OF A BME CURRICULUM

Willis Tompkins, University of Wisconsin, Madison

Using Design as the Backbone of a BME Curriculum

Willis J. Tompkins

Department of Biomedical Engineering
University of Wisconsin-Madison

Abstract

In this paper, I summarize my experiences as an advisor supervising biomedical engineering design projects in three different programs: 1) first-year design course that includes only freshmen but has students in each design group who will ultimately major in different engineering disciplines, 2) the EPICS (Engineering Projects in Community Service) program that includes in each group students from several engineering disciplines and is vertically integrated with students from different class years from Freshman through Seniors, and 3) the design courses that all biomedical engineering students are required to take every semester.

Introduction

“Science studies what is; engineering creates what never was.” So said rocket engineer, Theodore van Karman. When we created our new undergraduate degree in biomedical engineering at the University of Wisconsin-Madison, we were concerned that students would be getting too much of the knowledge of science and not enough of the spirit of engineering. This concern was in part due to the extra courses in life sciences and organic chemistry required in biomedical engineering that most engineering majors do not take. Therefore we decided to use the attribute that best defines engineering — design — as the backbone of the curriculum. After admission at the beginning of the sophomore year, all biomedical engineering majors take a design course every semester throughout their curriculum. These six design courses constitute a total of eight degree credits.

All engineering students at Wisconsin start in pre-engineering during their freshman year and are not admitted into departments until the sophomore year. We strongly recommend to students intending to become BME majors that they elect to take the general Freshman engineering design course called Introduction to Engineering during their first university semester. This course includes students from all disciplines. In their second semester, we recommend that they enroll in a biomedical engineering project in the EPICS (Engineering Projects in Community Service) program. EPICS provides a design experience that includes all disciplines and vertically integrates students from all college years.

For all these design courses—Freshman, EPICS, and BME—we solicit real biomedical engineering projects from faculty throughout the university, particularly from medicine and the life sciences, and from industry. Groups of students interact with these clients to define the

specifications for their projects. All groups are required to build prototypes over the course of a semester. I have taught all three types of courses and have summarized my experiences in this paper.

Freshman Design Course

The first-semester freshman course, Introduction to Engineering, is a three-credit course that meets for two 50-minute classes and one three-hour lab per week. The enrollment is limited to about 250 students. The course staff consists of a group of faculty and senior student assistants (SA) from different departments. In addition, several graduate students are employed as teaching assistants (TA) to support the course by doing such tasks as maintaining the web site and helping to procure parts to support the various design projects. All 250 students attend the lectures together. Some example topics of the lectures are the basics of the design process, maintaining an engineering lab notebook, industrial case studies by engineers from local industries, effective presentation techniques, engineers and society, and ethics. In addition, each of the 10 engineering degree programs makes a short presentation about their particular brand of engineering in order to acquaint the Freshmen with the various engineering specialties. Also, five lecture periods are allocated to parallel sessions in which faculty in the various disciplines present skills modules on topics such as electric circuits, mechanics, and materials. Students select the sessions most relevant to obtain knowledge they need for the construction of their project.

The 250-student class is divided into design teams of 12-13 students. Each team has a different project and a different client, so the class works on 20 simultaneous projects. Each team meets in a lab for three-hours per week. The lab facility is constructed so that two teams can meet simultaneously in adjoining lab rooms. Each lab room has an assigned SA, who serves as a senior mentor to the students of his/her assigned team. This strategy permits a faculty member to supervise two teams simultaneously with the help of the SAs. At the beginning of the lab periods, there are short group activities that build on the topics discussed in the lectures such as team building and brainstorming exercises.

At the beginning of each week, the course staff including the faculty, SAs, and TAs, had a one-hour meeting to discuss the lecture and lab activities of the week and to plan the activities of the following week. This meeting was extremely important to keep the design process proceeding on schedule in all the lab sections.

In the semester that I taught the course, I chose biomedical engineering projects for my two teams from a list of potential design projects solicited from across the university and from non-profit organizations. The client for one project was a physical therapist from the Veterans Administration Hospital who worked with Parkinson's patients. The students developed the following problem statement: Patients with Parkinson's disease often "freeze up" and cannot move when undergoing over-learned processes such as walking. Our goal is to create a device that will allow Parkinson's patients to consistently "unfreeze" themselves without outside assistance. For the second project, the clients were the care-giving mother and her teenage son who had cerebral-palsy, to whom a social service agency had referred us. The team's problem statement was: A teenager with cerebral palsy needs an open/close switch to operate his

computer that he can operate the switch with the left side of his head from any position in his bed.

For the first third of the semester, we divided the teams into subgroups of four or five students each. The subgroups worked independently to create the best conceptual design to solve their team’s problem. The subgroups then made presentations to the rest of the team with the client present in order to “sell” their idea as the best approach to pursue for the rest of the semester. The subgroups then formed back into their 12-13 person teams, and the teams continued the design process with the goal of implementing the final prototype. Both of my teams produced functional physical prototypes of their designs. Both teams learned to use tools in the College of Engineering machine shop to implement their prototypes, and one team also had to learn to solder to build a simple circuit. The semester culminated with each team presenting a PowerPoint presentation of their design to the rest of the class.

Biomedical Engineering Design Curriculum Backbone

Figure 1 shows the design backbone of the BME curriculum. As William Butler Yeats said, “Education is not the filling of a pail, but the lighting of a fire.” We are attempting to light fires with the design sequence.

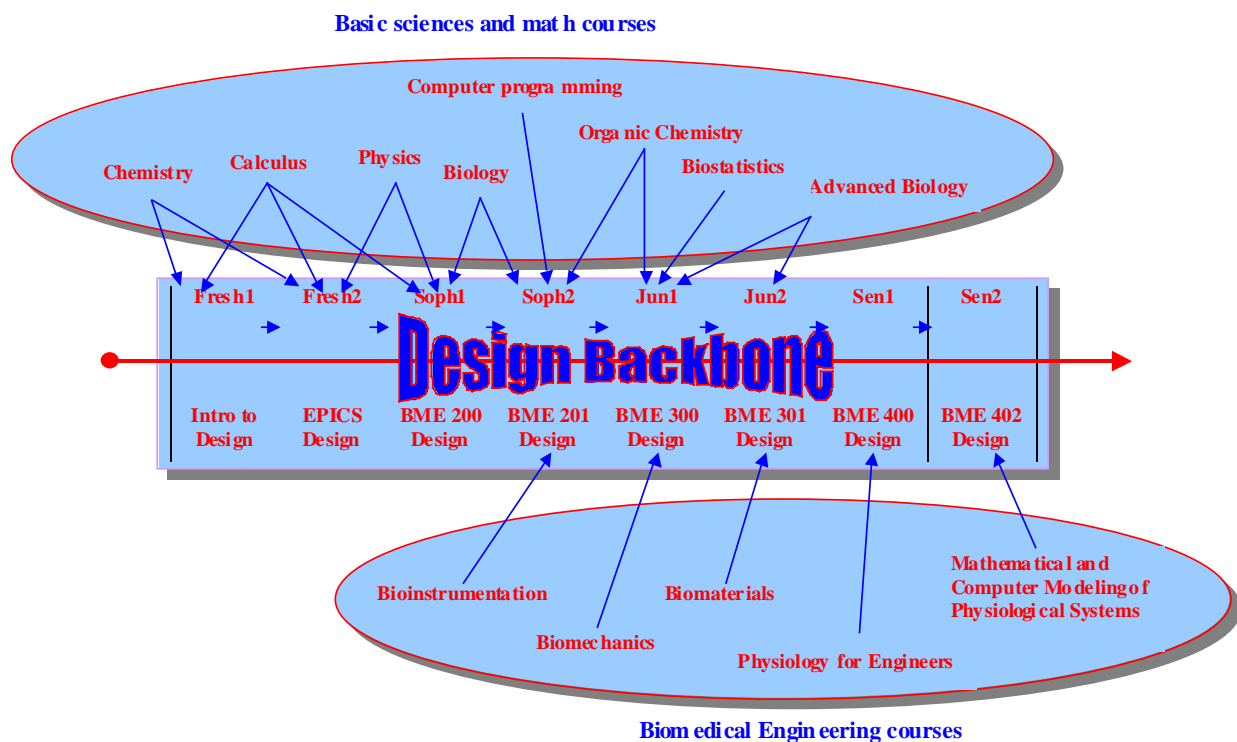


Fig. 1 A sequence of design courses serves as the backbone of the BME curriculum.

BME majors take BME design courses starting the first semester of sophomore year and continuing every semester throughout the curriculum. All the courses are one credit except in the

first semester of senior year when the course is a three-credit capstone design course. The top part of the Figure shows most of the required basic science and math courses and where they are taken in the student's curriculum. The bottom part of the Figure shows where the required biomedical engineering core courses enter the curriculum. We see the design sequence as the backbone of the curriculum, a theme that continues throughout their degree program, where students have the opportunity to apply the knowledge that they are gaining in their other courses and to see the relevance of the material that they are learning.

Like the freshman course, all the design projects are client-based, real-world design problems, solicited primarily from the medical and life science faculty around the university, although we have also completed several projects with a local biomedical company. We limit the projects to be those that require building a physical prototype. Unlike the freshman course, there is no SA or TA support. Faculty are responsible for all aspects of the course. Each faculty member has a weekly two-hour meeting in a computer lab with his/her teams.

The courses are organized as shown in Fig. 2. First-semester sophomores are each paired with first-semester juniors, who serve as peer mentors. A design team typically consists of eight students—half sophomores and half juniors. As in the freshman design course, the team is divided into subgroups which individually develop a conceptual design for the first third of the semester. In this case, the sophomore-junior pairs form four subgroups. In this approach, the sophomores have the opportunity to learn the design process from the experienced junior mentors. For the final two-thirds of the semester, the subgroups group together as eight-person teams to do the final design and prototype implementation. The added bonus of this approach is that the sophomores get to know a more senior student, who can serve as a peer advisor on issues such as course and area choices that go beyond the immediate goals of the course.

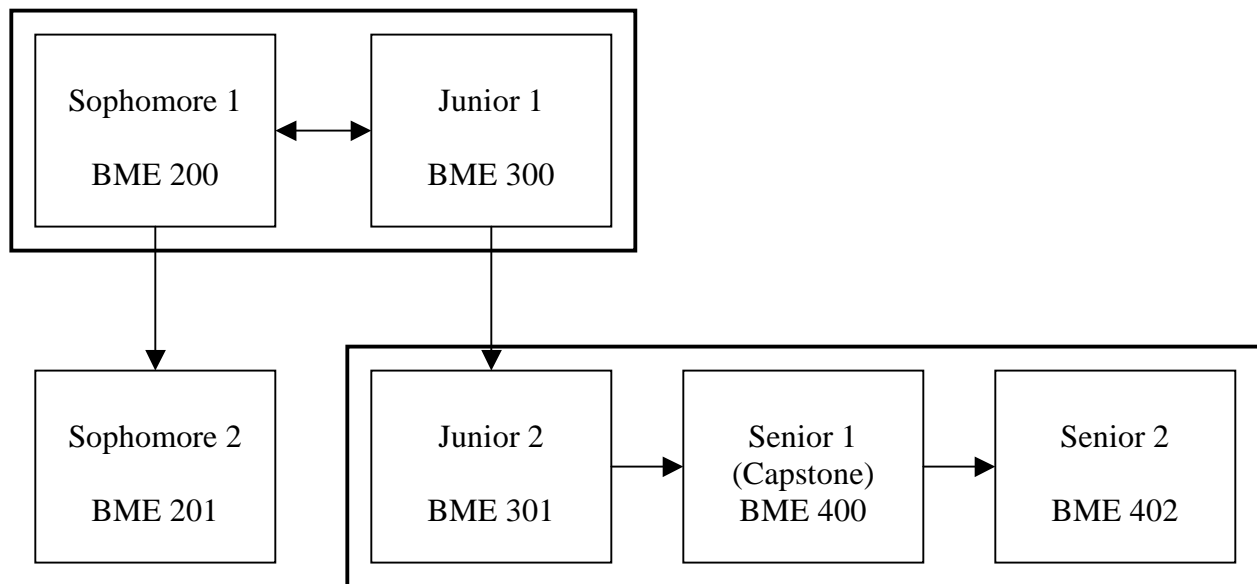


Fig. 2 Functional grouping of BME design courses.

After the first semester sophomore-junior experience, the second semester sophomores work as eight-person teams on different design projects. The juniors begin a three-semester design sequence that starts with planning and pilot studies intended to lead to the three-credit capstone design project in the first semester of their senior year. Their final one-credit design course in the last semester of their degree program is dedicated to testing, evaluation, and documentation of their capstone design project. Also they have an outreach requirement in which they must do a presentation in a K-12 school about their design project.

I was one of the four BME faculty advisors for the BME200/300 courses in Fall 2000. We had a total of 64 students—32 sophomores and 32 juniors. They were divided into eight teams of eight students each. So each faculty member was responsible for advising two design projects. We met with our two groups together in the same computer lab for a two-hour period each week. We limited our discussions at the beginning of each lab to 20 minutes. In these sessions, we focused on such topics as the design process, ethics case studies, and human and animal research protocols.

The client for one of my teams was a rehabilitation medicine physician. The problem statement developed by this team was: “The goal is to develop a device to enhance and monitor back exercise. This device will provide feedback to the patient and therapist regarding the spine position and tension in the abdominal muscles to obtain maximal benefits from continuing therapy.” The client for the other team was a psychiatrist. The team’s problem statement was: “To design and construct a cage-mount device for quantitation of both fast (startle response), general motion, and activity of the rhesus monkey.” The first team produced a very novel functional physical prototype and a Java applet application so that the device could be used with any computer. The second team decided to use a force plate system that the client agreed to purchase for about \$12,000. However, this system was not delivered by the end of the semester, so a physical prototype was not realized. As part of the design, this project required a special machined interface to connect the force plate to the cage and custom software to analyze and display the data summarizing the monkey’s motions.

As part of the course, we assembled a Biomedical Student Advisory Committee (BSAC). Each of the design teams provided one member for this committee. The charge of the committee was to provide feedback to the faculty for improving the design course sequence. This was a very active committee that met biweekly and provided us with many interesting suggestions.

EPICS (Engineering Projects in Community Service)

This student design concept was started at Purdue in about 1995. Our program evolved from the one at Purdue and was offered for the first time at Wisconsin in Fall 2000. I was one of the faculty advisors for the program in its first semester which attracted about 70 students and started seven new design projects. I supervised one of these projects. EPICS is a multidisciplinary, vertically-integrated approach. Teams are typically composed of 12-15 students from multiple engineering disciplines as well as other majors such as business and art and include students from different class years from freshmen through seniors. Unlike the freshman and BME design courses, the EPICS program restricts its clients to non-profit organizations as opposed to individuals. The intent is that a team, once assembled to support a non-profit organization, will

continue solving design problems indefinitely for that organization and will continually be revitalized by new students joining the team as students graduate or leave for other reasons. We permitted BME majors to participate in EPICS instead of our department design course provided that they chose one of the three EPICS projects that were classified as biomedical engineering.

I advised the team assigned to one of the three biomedical engineering projects. My team was composed of 12 students with the following classifications: five BME sophomores, three BME juniors, three ECE seniors, and one industrial engineering senior. The client was the university's Communicative Disorders Department. The team's problem statement was: "The goal of this project was to design an affordable feedback device that would minimize the need for voice therapy sessions for patients with the loss of speech intelligibility. It was to alert the user when his or her voice intensity had fallen below a specified threshold. This device was to be easy to use, lightweight, portable, and unobtrusive." This group divided into four sub-teams to work on different elements of this design. They were the transducer, analog, digital, and feedback sub-teams. By the end of the first semester, this team had produced elements of a physical prototype but they were not integrated together into a functional system. With the EPICS approach, some members of the team return for subsequent semesters, improving the likelihood of ultimately producing a fully functional prototype.

As in the BME approach, we formed an ESAC (EPICS Student Advisory Committee) composed of one student from each design team, which provided us with feedback throughout the semester.

Unlike the freshman and BME design courses, in the EPICS program, each team is expected to create and maintain a web site with all relevant materials about their project, including reports and presentations. Therefore, one member of each team has the special role of webmaster for the team. I believe that this is especially important for the EPICS program, because EPICS has the stated goal of supporting a client indefinitely. The web site serves as a valuable archival mechanism which future team members can use to study the approaches and accomplishments of the teams in prior semesters. The web site also serves as a publicly available source of information for the client organization and other members of the community.

Discussion

Table 1 shows some metrics of the three different design course approaches that I have described. Note that the faculty to student ratio is about the same in EPICS and BME design approaches, but the team size in BME is limited to eight students.

Table 1 Design course metrics.

Course	Team size	SA / student ratio	TA / student ratio	Faculty / student ratio	Teams per faculty
Freshman design	12-13	1 / 13	3 / 250	1 / 26	2
EPICS	12-15	0 / 70	1 / 70	1 / 15	1
BME design	4 or 8	0 / 64	0 / 64	1 / 16	2 or 4

All three of these design courses have some common deliverables, including the following.

1. Each student keeps an engineering notebook.
2. Each team produces an end-of-semester report.
3. Each team does an end-of-semester PowerPoint presentation.
4. Each student does self and peer evaluation.

The various courses have differences in other types of deliverables, such as the content of weekly progress reports. They also have varying levels of staff support. But the principle difference is the types of backgrounds of the students in each course.

The freshman course is restricted to first-semester freshmen, so none of them have yet had an engineering course, and many of them are destined leave engineering and go on to other majors. Since they have no engineering expertise or knowledge, there are severe limitations on the types of projects that they can successfully complete.

The EPICS program mixes together students from different disciplines who have very different levels of expertise. Since most real-world projects are multidisciplinary, EPICS possibly provides the most realistic approximation to an actual workplace model. Also unlike the other courses, EPICS has the expectation that a team will continue to serve the same client indefinitely, so the projects do not have the artificial time constraint of a single semester to produce the final result.

The beginning BME design courses use junior students to mentor sophomores, which I think, is a valuable approach. The course structure also provides a three-semester junior-senior design sequence so that projects can be conducted over a reasonably long time span. Although all the BME students are in one department, they each have traditional engineering concentrations (e.g., bioinstrumentation, biomechanics), so a BME team is by its nature multidisciplinary. However, ultimately BME graduates will work with engineers in other disciplines, so it would be valuable for them to get some of that teamwork experience in the university.

Summary

It was Herbert Hoover who said, “To the engineer falls the job of clothing the bare bones of science with life, comfort, and hope.” With our design courses and particularly the design backbone of the BME curriculum, we hope that we are helping BME graduates to see how to “clothe the bare bones of science” regardless of whether they choose to continue their careers in engineering, medicine, or any other field.

Acknowledgements

Development of the biomedical engineering design sequence was supported in part by a Whitaker Foundation Special Opportunities Award. The faculty who have contributed to developing and teaching this sequence are David Beebe, Frank Fronczak, Jordan Lee, Mark Nicosia, Nimmi Ramanujam, and John Webster. The EPICS program is supported by an NSF

grant administered by Purdue University called, The EPICS Consortium: A National-Scale Service Learning Program in Engineering.

Bibliography

1. For more information about the freshman design course, see: <http://www.cae.wisc.edu/~epd160/>.
2. For more information about EPICS at the University of Wisconsin, see: <http://epics.engr.wisc.edu/>.
3. For more information about the biomedical engineering curriculum at the University of Wisconsin, see: <http://www.engr.wisc.edu/bme/>.
4. To learn more about the BME design courses, go to: <http://www.engr.wisc.edu/bme/courses/> and select the courses, BME 200, 201, 300, 301, 400, and 402.

WILLIS J. TOMPKINS

is Professor of Biomedical Engineering at University of Wisconsin-Madison. Dr. Tompkins received the B.S. and M.S. degrees in electrical engineering from the University of Maine and the Ph.D. in biomedical electronic engineering from the University of Pennsylvania. He has served in the past as Chair of the ASEE Biomedical Engineering Division (BED).