Sprints vs. Marathons: Two Potential Structures for Assigning Engineering Design Projects.

Paul D. Schreuders, Arthur T. Johnson
University of Maryland, College Park

Abstract

While a major goal of an engineering education is the preparation of students for solving "real world" problems, actually assigning these problems is rarely possible in a teaching environment. A number of different strategies exist for structuring student projects, so that they prepare the students for the work environment. We will compare the benefits and the costs of two of these strategies for structuring student projects. Both methods are currently employed in the Biological Resources Engineering Department at the University of Maryland. Furthermore, both strategies, described below, have their strengths and weaknesses.

In the first, more common, structure, students are assigned group projects that last the entire semester. The time available allows the assignment of complex and relatively unbounded projects, and the students can be exposed to the entire process of project development. However, because of the duration of the project, only a single iteration of this process is possible. Furthermore, in practice, the majority of the project tends to be performed in a short period of time, just prior to the due date.

An alternate strategy is to assign a number of short projects throughout the semester. In this approach, three high intensity, short duration projects are assigned. The students must build expertise in an area in a matter of only a few days, requiring them to develop both research and time management skills. In addition, because multiple projects are assigned, projects may be assigned in different disciplines and the students have several opportunities to correct their mistakes and polish their report writing skills. However, because of their short duration the projects must be somewhat limited in scope. Furthermore, because of the short duration of the projects, the students become completely immersed in their projects, to the exclusion of their other classwork.

Introduction

Biological resources engineering is a response to the need that exists for engineers with dual expertise in engineering and biological systems. Biological engineers apply engineering principles, analysis, and design to a diverse range of problems, including aquacultural engineering, biomedical engineering, biotechnology, environmental and ecological engineering, food engineering, and water resources engineering. This diversity of application requires breadth of education. The Department of Biological Resources Engineering at the University of Maryland has developed a curriculum that is both broad and fundamental. All of our students acquire skills in mathematics, biology, chemistry, microbiology, and cell biology. These skills are coupled with strong engineering fundamentals, such as circuit analysis, mechanics, fluids and thermodynamics, to provide the foundation for their upper level courses.

During their junior and senior years our students take courses that emphasize the interactions between engineered systems and biological systems by examining the engineering properties of biological materials, by designing and controlling biological processes, and by performing engineering analyses on biological and environmental systems. Two of these courses are Biological Process Engineering and Biological Responses to Environmental Stimuli. The former course studies the transport processes of fluid flow, mass transfer, and heat transfer with an emphasis on the design of processes and products involving biological materials or systems. The latter course considers the adaptations to engineering analysis that must be made in order to accommodate living systems. In addition, this course applies the techniques of engineering analysis to living systems, such as human thermoregulation and population dynamics.

Throughout these courses, we have integrated design projects as a means of fostering practical skills such as problem identification, problem solving using teamwork, and communication in both oral and written formats. However, while many of the goals are common, there are some striking differences in how these projects have been implemented. In the remainder of this paper, we will compare and contrast these two project paradigms and examine their impact on student learning. The project structure described in the left-hand column is that used in Biological Process Engineering. The structure described on the right-hand side is that used in teaching Biological Responses to Environmental Stimuli.

The Motivations and Benefits for the Project Structures

A major motivation for the structure of our projects is to, within the confines of an academic setting, provide design experiences and develop skills that are directly applicable to our students needs after graduation. Career choices for Biological Resources Engineering graduates are as diverse as the program. Our graduates have found careers in academic, research, and outreach education at universities; with consulting firms; in manufacturing; and with both regulatory and research governmental agencies. The choice of project topic is a major consideration in the development of the project's applicability. The topic must not only provide a realistic problem but must also support and extend the materials covered in the classroom.

Biological Process Engineering

My course is taken in the spring semester of the junior year, and is the first real upper level design course taken in their curriculum. Thus, I am building a foundation of the basic design skills which later teachers can build upon.

All of my projects are commercially inspired. My sources include industry/ consultant contacts or trade journals. Thus, the projects I assign to students are ones with real meaning at the time. One project, delivery of a cystic fibrosis gene, was a current project of Gen Vec, Inc., and another, drying of taxus wood chips, was so current that industry was extremely reluctant to provide background information. My students are working on state-of-the-art projects.

With one fluid flow project, one heat transfer project, and one mass transfer project, the three projects can be made independent of one another. At one time I experimented with a theme that ran through each project, but with the breadth of appli-

Biological Responses to Environmental Stimuli

The students in this class are in the final semester of their senior year. Thus, this course builds a superstructure onto the foundation laid down during their academic career. The projects are aimed at forming a synthesis of their previously acquired knowledge and skills.

Real world engineering projects require fulfilling diverse and, often, conflicting needs. My projects are chosen to challenge the students by developing designs that consider both the animate and inanimate components of that design. In addition, the designs must also meet the needs of a "client."

My students most recent project involved the development of self-contained "zoo modules" for inclusion in a shopping mall. In this project, the students were asked to present a design for an enclosed living space for animals that met the health and welfare needs of the animals, fulfilled the regulatory requirements of the government, and met the needs of the mall's sponsors and designers.

cations and interests of our current biological engineering students, three different applications areas are much more desirable. In this way, all students feel that there is something in the course for their particular interests.

Three projects allow for three assigned and different applications. These applications are medicine, environment, and food or biotechnology. All students in our program are thus able to deal with problems in all these applications. Our students are stronger and more versatile as a result.

I have experimented quite a bit with course requirements. I found that after the first design project there were quite a few students who still did not know how to define a problem, gather information, budget their time, judge when to switch from information gathering to production of output, produce an acceptable (although not necessarily optimal) solution, and write an attractive report. After the second project, there were still some students who did not do this well. But following the third project, there was no one who didn't have a good idea about how this process works. Repetition builds skills reinforcement. My students need three projects before I am confident that they can be good engineers.

Problem descriptions are given to students verbally. I will not hand out a written description because I believe that the design problems they will encounter after graduation will be given verbally in many cases. Furthermore, there are often essential pieces of information that I purposely withhold until they ask a question that will provide that information. This is because students must know how to define their problems themselves. There have been times when students have not asked sufficient questions and have had more difficult times as a result. When I answer questions, I play as if I am a client, and I won't know what they ask if the question is too highly technical. Students don't know how to deal with this approach at first. Up until my course, they have been given the highly structured problems at the end of book chapters, and each problem had one answer.

In this case, the "client" requested that the display draw customers to the mall and contain educational materials. Furthermore, in the request for proposals, the client requested two progress reports and a final report. The format of all of the reports was specified.

This breadth of needs benefited from the diversity in our student's areas of specialization. For instance, the aquarium module from one student's interest in aquacultural engineering and another's interest in the removal of ammonia from agricultural waste streams.

The project description was provided in the format of a "request for proposals." Only a general concept was specified and I intentionally avoided detailed specifications for the project. This mirrors commercial projects where the design constraints are often poorly defined, but there is a desired result.

During the project, the students develop the ability to define the boundaries of project, structure the solution into a manageable form, and present a solution within the confines of the schedule that they have created. Because my students are already competent at other project skills, I have the opportunity to assign projects of greater scope than is possible in a shorter project format and can structure the project in a developmental sequence.

One advantage of the longer project duration is that the students are given the option (not always taken) of distributing their work throughout the semester. This minimizes the impact of the project on other courses, a particularly relevant effect in any engineering curriculum. Furthermore, the projects are minimally impacted by short disruptions in the students life, such as illness.

Another aspect of project management is project scheduling. Engineers are often involved in long-term projects. My students are asked to develop a schedule for completion of the different phases of their project. After each phase of the project, my students are asked to comment on how well

Students initially show frustration and despair, until they gain confidence in their abilities to pose insightful questions. After that, they play along with the game.

One of the biggest real-life constraints is time. Engineers in industry or consulting don't have much time to produce their proposed designs: several weeks is often luxurious. Thus, students need to be able to make practical choices, gather information, and produce acceptable products under the pressure of time. This prepares them for real conditions on the outside. This has been confirmed by contacts in industry and consulting, and by past graduates of our program.

I try to assign projects that are of a magnitude that can be completed satisfactorily in the 10 days or so that I give the students to complete them. Also, the projects are chosen to exercise one of the transport processes of fluid flow, heat transfer, or mass transfer. These two constraints do bound the projects somewhat, but not as far as the students are concerned.

Students often complain to me that they can't get any work done in their other courses during the time they are working on my design projects. Of course, that is because they themselves put extreme priority on finishing these designs in an acceptable fashion. I might feel sorrier for them if I hadn't received enough unsolicited comments from past graduates that told me my course meant a lot to their successes.

Furthermore, the reports that I require are of a specified format that I have found to meet nearly all engineering design report needs. At the beginning of the course we talk about characteristics of the reader of the report. The client may or may not be technically knowledgeable, but she/he is most likely very busy. Thus, the report must be structured to have maximum communications impact. I want my students to know how to communicate with busy readers.

they have matched their timetable and to develop a new schedule based on their current progress. Thus, the students develop both skill at predicting their progress and (usually) at dynamically rescheduling the remaining tasks, so that the project is completed on time.

The first project report is a short, 2 page, preproposal. This is often the first occasion that the students have been requested to write with limited available space. This report motivates the students to begin their projects early in the semester and, because of the limited report length, concisely identify their projects' direction and goals. Because of this limited length, a detailed knowledge of the project material is not yet required.

A few weeks later, the students are asked to provide a detailed project description, of specified length and format. This description includes the project's current status, a technical outline of the project, the project's feasibility, and a schedule for the project's completion. In addition, each group is required to orally present their proposal to the class.

At the end of the semester, the students' final project reports are due. These include an extensive written project report and oral presentation of their design. Both of these reports have two components, an overview of the project for the management of the client firm and a technical description for the design engineers for the builder. The first component provides the students with experience in explaining technical topics to a non-technical audience. The second component ensures that the project's engineering component has been correctly performed.

The two approaches described within this section, while seemingly different, have much in common. Both are attempts to develop the skills needed in the work place. Whether in the form of a request for proposals or oral instructions, the initial project descriptions are somewhat vague and challenge the students to define the project.

Each of the two strategies meets the interests of a diverse student body. The structure of the Biological Process Engineering projects requires more tightly bounded projects, so the students' interests are met by choosing a variety of project types. The emphasis on a longer duration project and on synthesis in Biological Responses to Environmental Stimuli precludes this approach. Instead, the project topics are chosen to be sufficiently flexible that each group of students can work in an area that emphasizes their interests.

Project Outcomes

In our project paradigms we place emphasis both on process and product. The projects are planned and implemented so as to build fluency in teamwork, strength in interpersonal relationships, and effectiveness in communication. Each paradigm takes a different approach to building these skills. In particular, the paradigm used in Biological Process Engineering builds strength through short high-intensity sprints. In these sprints there is little ability to compensate for errors, so the job must be done right the first time. The paradigm used in Biological Responses to Environmental Stimuli, instead, builds strength by developing the skills required to pace oneself over a longer time period and in preparing the students to handle long term projects.

Biological Process Engineering

For all the intensity, and the lack of definition of acceptable outcomes, student efforts have always been much greater than I would have expected. I never tell the students what is acceptable, but I always tell them what is desirable. They always give me more than I could reasonably expect as requirements. This happened before I formed groups; now, with groups it happens even more. The reports and designs are incredible.

Once the projects are assigned, my students don't need to be externally motivated to complete their projects. The shock value (or abject terror) induced when they find that they have to produce an acceptable engineering design for an ill-defined problem about which they know little or nothing, and they have less than two weeks to produce the solution, is motivation enough indeed.

My groups are reconstituted for each design project. This is done to provide some uniformity of skills throughout the semester. In this way, several groups have the benefit of the best students and several groups have the burden of the worst. Students cannot say that they had an unfair lot because some

Biological Responses to Environmental Stimuli

As one might expect, since we are drawing from the same student body, the outcomes of my student project have been good. The students are self motivating and creative in their solutions.

One surprising aspect of the projects has been the rapid integration of new technologies into their research and communications techniques. In the research area, the students have made active use of the Internet as a source of graphics and information. However, as use of these resources has increased, I have found the need to provide additional information on the evaluation of nontraditional data sources and on the use of copyrighted materials. In addition the students develop skill in the graphical presentation of information. I see extensive use of color images and drawings in their reports.

The longer time allotted for my project allows the students to give oral presentations. These skills are increasingly important in the work-place, particularly as the cost of technologies such as video conferencing decrease. Once presentation software and an overhead projection panel were made available to the students, they student undermined their efforts for all three projects. Groups are exercised between projects with homework problems in an effort to force them to become functional as quickly as possible. These groups generally work well, and students who normally would not choose to work together find themselves working together through very intense, stressful, but short, times

Time constraints also mean that we don't have time for such nice things as verbal presentations and preliminary reports. I must cut through to the essence of my requirements: the written reports only

were quickly adopted. With the adoption of these presentation technologies, the students have also become aware of the hazards of depending on these technologies. These hazards have included incompatible software, hardware failures, and failure to properly set up the equipment.

Both of these structures emphasize the development of communication skills. In the case of Biological Process Engineering, writing skills are developed through repetition, and quick organization of a team is essential. In the case of Biological Responses to Environmental Stimuli, the students produce multiple types of written reports and presentations for different audiences. Furthermore, team management becomes essential since a non-contributing member's effect on the product is more evident.

Evaluation of the Projects

A final aspect of each project is evaluating its success. The student's work is evaluated using the project's reports and by comparing these materials with the specifications provided. Both of us rely on peer review as part of the evaluation process. The number of copies of the report submitted is the same as the number of groups. The teacher keeps one of these and one copy is given to each of the other groups. A peer evaluation form must be filled out for each report given to each group. This does several things: 1) it allows students to see others' reports, including good and bad aspects, 2) it gives the students practice in peer review, which they will need to be able to do after graduation, 3) it provides additional feedback to the originating group, and 4) it spreads the blame for good or bad grades given to reports. Peer evaluations are done anonymously, and they are completed before the reports are examined. Student evaluators frequently have more time to investigate details than we do. Thus, they can be very helpful.

Biological Process Engineering

Peer evaluation, especially with feedback provided by returned evaluation forms, enables students to improve their products on the next project. Because each project is structured similarly, peer review is particularly effective in providing a means to improve. Interestingly, the peer review process also can lead to definition of an "acceptable" product. Sometimes, based upon peer evaluation, members of groups begin to limit their design project efforts at the end of the course because their peer evaluations indicate that they have reached the desired level of quality.

Biological Responses to Environmental Stimuli

Peer review is used to evaluate both the full proposal and the final results. The actual review is completed in two parts.

The first evaluates the quality of the other groups' projects. Because each segment of the project is different, there is limited opportunity for positive corrective action. However, because each group evaluates the other groups, the students rapidly become aware of the deficiencies and advantages of various styles of presentation.

The second part of the review evaluates the

the desired level of quality.

Project grades are allocated uniformly: each member of the group receives the same project scores (one score for technical effort and one for communications). While that may not be entirely fair, because some members of the group contribute more than others, I do ask for each group to evaluate all members' efforts on the project. At the end of the course, I can look at the accumulation of effort evaluations for every member of the class; I reserve the right to add or subtract one letter grade from the final course grade depending on evaluations.

work distribution within each group. This is reported as a percentage of the total effort. The students are also asked to comment on the group's working dynamics. Based on this feedback, each student's grade is adjusted from the project's overall grade by up to 10 percent. The adjustments to the student's grades are zero-sum, based on the assumption that the group has compensated for any deficiencies in an individual's contribution. This grade differential motivates the students to contribute equally to the project.

Because each project group remains intact throughout the semester, there is the potential for one student to undermine the product of the group. The impact of this factor has been minimized by the manner in which grades are assigned. Furthermore, the non-contributing student has been more evident in the later peer evaluations. My experience is that a these students have been given the benefit of the doubt on the early peer evaluations. However, as the semester progresses the group members identify the pattern and respond accordingly. Similarly, a group becomes increasingly aware if a single group member continuously performs exceptionally.

Conclusions

While the project styles presented in this paper are significantly different, these differences build complementary skills in the students. The techniques used in Biological Process Engineering teach students to quickly come to grips with an unfamiliar topic and to rapidly formulate solid engineering designs. The techniques used in Biological Responses to Environmental Stimuli emphasize identification and definition of project goals and the project development sequence. Furthermore, the latter approach is dependent on the skills the students developed during the former. Perhaps of equal importance to the pure engineering skills developed during the projects are the time management and teamwork skills. The Biological Process Engineering project teaches the students to budget their time and to work with others in a time constrained situation. On the other hand, Biological Responses to Environmental Stimuli emphasizes longer term planning and working with others for longer periods of time. Both the project development skills and the management skills developed during these projects are critical elements in engineering practice and essential to the success of our students after they graduate.

Paul Schreuders

Paul Schreuders is an Assistant Professor of Biological Resources Engineering at the University of Maryland. He teaches Biological Systems Controls and Biological Responses to Environmental

Stimuli to seniors. His research interests include cryopreservation and the structure and function of bacterial biofilms.

Arthur T. Johnson

Art Johnson is a Professor of Biological Resources Engineering at the University of Maryland. Best known for his design work on the life support systems for Noah's Ark, he continues to tell bad jokes and to teach Biological Process Engineering to juniors and Bioinstrumentation to graduate students. His research interests include breathing and watching students run on a treadmill.