ON THE DIVERGENCE OF CASE STUDIES AND HARDWARE PROTOTYPES IN ENGINEERING INSTRUCTION

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Abstract

This paper discusses two different pedagogical methods for engineering design in undergraduate and graduate instruction: discussion of case studies and development of hardware prototypes. The goal of both methods is to provide a level of experiential knowledge not generally transferable through a conventional lecture format. Pedagogical investigations indicate divergence in the application and results of the two methods. Specifically, case studies have been found to stimulate significant interest and insight into professional issues while not always efficiently delivering engineering content. Meanwhile, hardware-centric approaches have been found to focus and motivate students but allow great variance in the subject, rate, and level of knowledge acquisition.

Introduction

While engineering education seems to have come under increased criticism lately [1, 2], it is interesting to reflect upon earlier but similar concerns of [3] and [4]. To summarize, Green et. al. determined that engineering education should have the following properties:

1. Relevance to the lives and careers of students, preparing them for a broad range of careers, as well as for lifelong learning involving both formal programs and hands-on experience;
2. Attractiveness so that the excitement and intellectual content of engineering will attract highly talented students with a wider variety of backgrounds and career interests—particularly women, underrepresented minorities and the disabled—and will empower them to succeed; and
3. Connectedness to the needs and issues of the broader community through integrated activities with other parts of the educational system, industry and government.

These attributes call for a high degree of "active learning." Active learning is a teaching method that forces students to think about, apply, and comment on the information being presented [5]. The goal of this strategy is to convert passive listening to engaging analysis, synthesis, and evaluation of engineering methods. Both case studies and hardware projects are methods for active learning in engineering education. This paper will next describe the two methods in more detail. Afterwards, discussion will be presented regarding the methods' divergence.

Overview

Case Studies

The term 'case study' typically refers to a written account of real events, or a construction of events that could reasonable take place. An engineering case study usually tells a story from the perspective of one of the principal design engineers interacting with management, customers, manufacturing, and testing. The fundamental tenet in the case method is that the best way to learn a skill is to practice. Few of use, for example, would want to hear a concert pianist who had attended many lectures on piano playing but had never touched a piano [6]. We hope that very few engineering students will internalize the failure modes of an engineering design through direct experience. However, we can try to provide similar engineering insight through case study of those same failure modes in engineering instruction [7].

The faculty of Harvard University have developed an extensive library and forum regarding the use of cases in college instruction. According to Shapiro, the total case process consists of four steps:

1. individual analysis and preparation;
2. informal small group discussion;
3. classroom discussion; and,
4. end of class generalization about the learning.

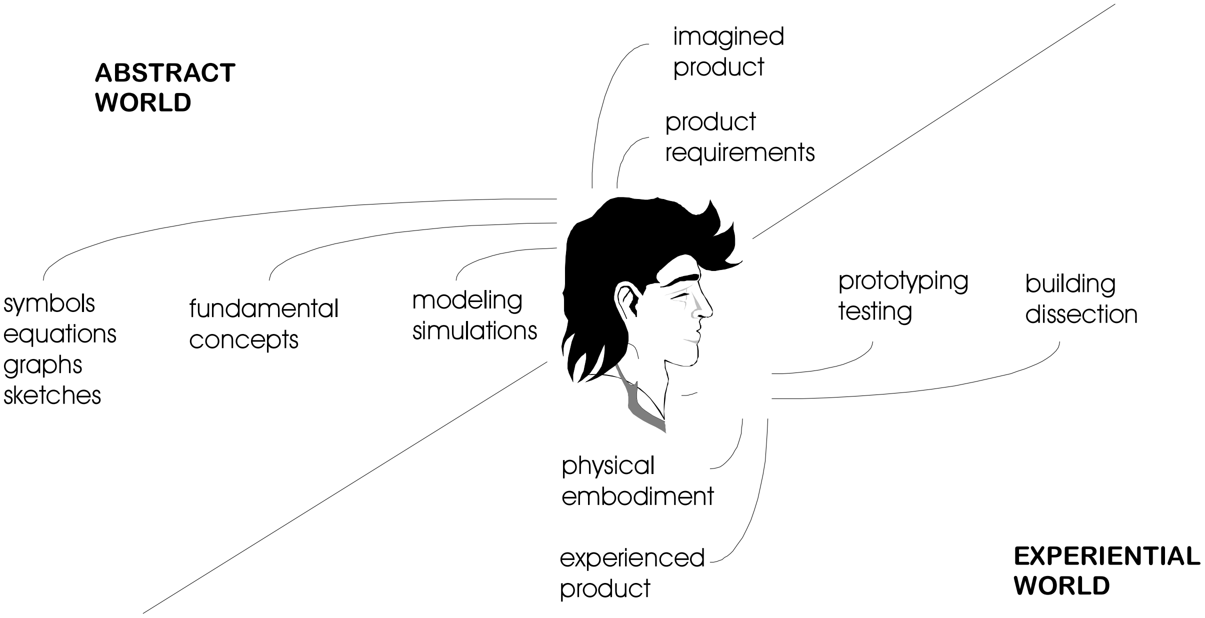

Figure 1: Abstract and Experiential Domains in Engineering

The information contained in most engineering case studies is fairly complex (including detailed drawings, material property data, analytical models, etc.) though simpler case studies due exist to illustrate a difficult human situation requiring a decision. Several hundred case studies have been developed for different levels and domains of engineering education. Stanford University's School of Engineering developed a fairly large set of detailed cases in the 1960 and 1970s, which is now maintained by Rose Hulman Institute of Technology and Carleton University [8]. Though many cases are lacking adequate instructor notes and many others need to revised to current day practices and typography quality, most cases provide significant value in engineering education.

Hardware Projects

A fundamental tenet of many engineering educators is that students learn by reflecting on their physical experiences and by linking and contextualizing theoretical and practical knowledge [9]. Fundamental engineering concepts such as energy, momentum, and torque are frequently used in engineering education and practice. However, a large body of research in physics learning shows that students have difficulty connecting abstract concepts to their experiential understanding [10]. A series of impromptu estimation questions asked of graduating seniors from MIT revealed similar issues in Engineering Education [11]. When asked how much energy was in a 9 Volt battery, 10% of the students did not reply in a correct system of units and the magnitude of the remaining answers varied by nine orders of magnitude!

The relationship between abstract and experiential domains is shown in Figure 1. The vast majority of engineering instruction is abstract. As such, students may not physically understand a stress of 20,000 psi, a velocity of 40 meters per second, or a density of 8.7 grams per cubic centimeter. It can thus be extremely difficult for students to properly formulate engineering problems, analyze systems, interpret results, and synthesis design solutions. Laboratory courses and (more specifically) hardware-centric senior design courses attempt to provide experiential basis for the students to apply their abstract knowledge to 'real' engineering problems.

There are some difficult challenges to incorporating hardware projects into the engineering education. Implementation issues of hardware projects may include but are not limited to materials budgets, student safety, time constraints, project selection, project mentoring, instructor resources, performance evaluation, etc. With all these issues, however, many engineering educators and alumnae believe that hardware realization and testing is fundamental to professional development.

Disclaimer

The author's 'hardware' experience as an instructor has been augmented by industry experience as an applications engineer at General Electric as well as a very experimental doctoral research program.

Exposure to the case method of teaching was provided through the Graduate School of Business at Stanford University.

The author has taught the Mechanical Engineering senior design capstone course (MIE415) four times at the University of Massachusetts Amherst. The author has also taught a graduate-level course in Mechanical Systems Design (MIE760) as well as a senior-level Production Scheduling and Control course (MIE477). All of these courses have utilized engineering analysis, written reports, industry projects, hardware realization, and case studies to varying degrees. For instance, MIE415 utilized National Society of Professional Engineers (NSPE) case studies to discuss ethics but culminates written reports and/or hardware realization. MIE477 utilized industry projects and 'real' production operations as a basis for learning and applying scheduling concepts. Likewise, MIE760 utilized redesigns of existing hard products (such as servovalves, power amplifiers, toner cartridges, etc.) as well as Stanford University engineering case studies.

Multiple teaching reviews and surveys were conducted in each of the courses offered by the author. Every attempt has been made to fairly represent the judgements rendered in this paper and how they apply to engineering education. However, the author does not warrant or imply that the methods discussed in this paper will produce similar results for other instructors.

Attribute Divergence

Little debate is likely required to agree that engaging the students in a thoughtful conversation about engineering will produce more capable graduating engineers. Both case studies and hardware projects have been proposed as methods for active learning in engineering education. The attributes of these two methods will now be compared. Afterwards, the paper will conclude with some situational analysis and guidelines for method usage.

Content Delivery Efficiency

Traditional engineering lectures provide the most efficient means of delivery engineering content to the students. This is because the instructor maintains full control of the class agenda, is able to prepare a refined set of notes, and is provided maximal time to broadcast this information to the students. Regarding case studies and hardware projects, we can likely agree that case studies provide a more efficient method of content delivery than hardware projects. Case studies can be used as a compliment to traditional lectures, well-structured around a refined set of concepts, and discussed in a fairly typical classroom setting. Hardware prototype development, however, may not map linearly onto a course outline – certainly not when many different hardware projects are being conducted as in a senior design course. As such, the delivery efficiency of traditional lectures gives way to more detailed explorations of implementations and behavior.

Content Retention

Yet pedagogical research has shown that long-term content retention has little connection to either the amount of content delivered or delivery efficiency (REF). On a concept by concept basis, hardware exploration might provide the greatest probability for concept retention. Consider the development of the compact 30 Watt generator shown in Figure 2. The students had taken courses in mechanical components, feedback theory, and design. However, during hardware realization they internalized some core engineering concepts not received in courses:

- development of a physical feedback throttle mechanism for controlling motor speed from centrifugal force;
- devising a method for measuring torque and power output, then rewinding the generator coils to achieve the proper voltage and amerage performance;
- recognizing the infeasibility of direct drive between motor and generator, and devising a clutch mechanism to transmit power;
- development of voltage regulation and adjustment circuits for electrical power output;
- assembling and packaging all components into a robust and minimal product.

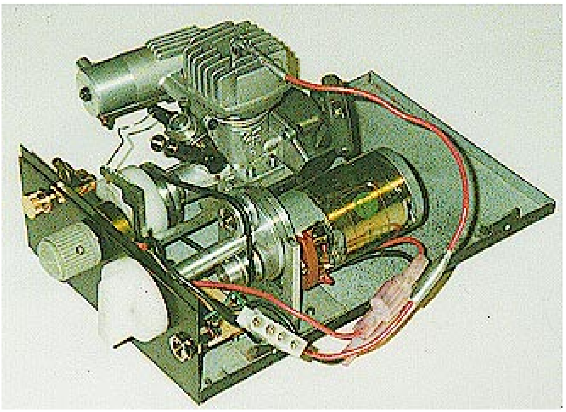

Figure 2: Perceptual Map for Content Delivery

Case studies may also provide for greater content retention than traditional lectures. By forcing independent thought and critical judgement of the engineering situation and methods, the student internalizes not only the abstract engineering content but also the application of the abstract engineering content. The result is a greater ability to apply the engineering principles and, hopefully, a greater retention of the fundamental concepts.

Figure 3 provides a perceptual mapping of some different educational methods as a function of content delivery efficiency and content retention. While the individual instructor will have a large effect on the exact placement of these points, it is interesting to note that an inverse relationship seems to exist between efficiency and retention. Further education research is necessary to precisely define the underlying causes and develop more effective methods for engineering education.

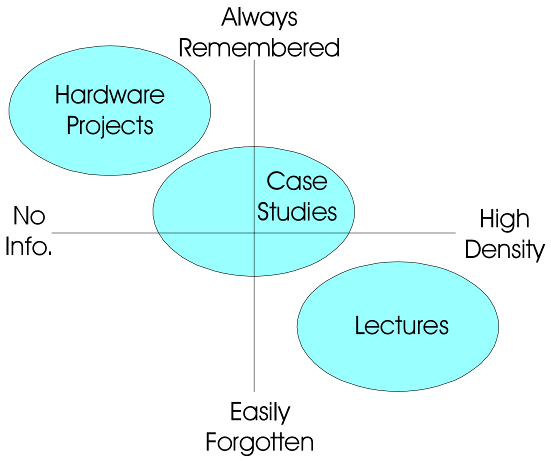

Figure 3: Perceptual Map for Course Content

Domain Coverage

It is a fact that case studies and hardware prototypes may not provide adequate domain coverage. For instance, it may not be possible to utilize either method for investigating the atomic behavior of electrons in a transistor, fluid flow through a complex chemical process, or transverse loads in concrete foundations. In these instances, traditional lectures are not only the most efficient means of content delivery, but also provide the only method of adequate domain coverage. As such, domain coverage is the greatest barrier to utilizing either case studies or hardware projects.

Providing Wisdom

One of the great motivators for utilizing case studies and hardware projects beyond increasing active participation is the real possibility of providing wisdom that can not be taught through any other method [12]. Many engineering faculty have an unrivaled breadth and depth of knowledge in their domains. Students frequently laud the faculty for their specific expertise. Yet a traditional lecture format (in which the instructor detours for five minutes to discuss a specific experience) usually does not provide a reasonable mechanism for sharing such wisdom.

The case method is significantly more powerful in that such wisdom can be honed to an exact message, then augmented with ample and relevant detail to ground the experience. With this description, the student can be asked to perform critical engineering analysis before class. The case itself can then be discussed at length during the session with the students acting as real practitioners in the case. The result is that much of the wisdom of the initial case writer is captured and conveyed to the students.

The hardware realization approach provides a similar mechanism for familiarizing the students with abstract engineering concepts. Such wisdom, however, is largely limited to the physical domain of systems and devices, whereas case studies can cover human and physical domains. Figure 4 provides a perceptual map comparing different engineering education methods according to domain coverage and wisdom. The impact of this and other perceptual maps will be further discussed in the conclusions.

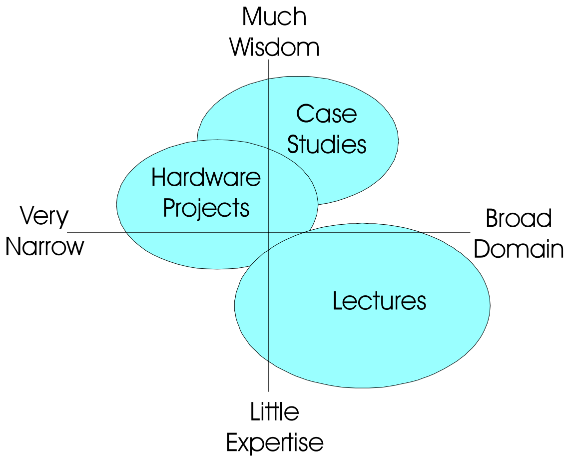

Figure 4: Perceptual Map for Domain Coverage

Student Immersion & Motivation

Most instructors have at times felt disconnected from the students, perhaps triggered by the immobile and blank faces of many of the students indicating their lack of interest in the lecture material. Active learning attempts to reduce the likelihood of such situations by 'immersing' the student directly into the lecture content and providing a mechanism for active consideration and involvement. Both case studies and hardware projects are significantly more immersive than traditional lectures. Both methods require active participation by the student to achieve the course goals.

It is often difficult to interpret the level of individual student activity in case studies and project teams. The author has felt that certain case studies and projects were complete failures, only to find months or years later that the students found significant value in their experience and was able to apply the skills later in professional practice. However, it should be noted that both case studies and hardware projects have increased variance in the quality of the students' experiences. The fundamental limitation in these teaching methods is lack of control in student activities. Since the instructor is not able to force a certain chain of thought in these interactive methods, the student will largely determine the quality of their educational experience. While these methods may provide increased immersion and motivation, indolent students may learn more by attending a course utilizing a traditional lecture format.

Evaluation

Evaluation is also more difficult with case studies and hardware project methods. In business education, student performances in large case classes are often scored by a teaching assistant based on number of points discussed rather than the quality of the discussion being generated. This type of active learning format (in which the students must actively challenge other in the class to be heard and understood) may increase the likelihood of career success. While written reports and other evaluation mechanisms can be utilized, the precise evaluation of case performance is not a trivial task.

Evaluation of hardware projects may be even more difficult. There is a very real possibility for hardware realization to occur in the complete absence of engineering analysis or synthesis. In such a case, it can be difficult to assess how much the students learned or achieved. Alternatively, a team may perform extensive engineering development yet fail to produce a functional prototype. In the case of design shown in Figure 2, the final device was initially functional yet failed after a twenty minutes of operation due to creep in the rubber transmission belt. As a result, the team did not score an 'A' even though they had learned a significant amount.

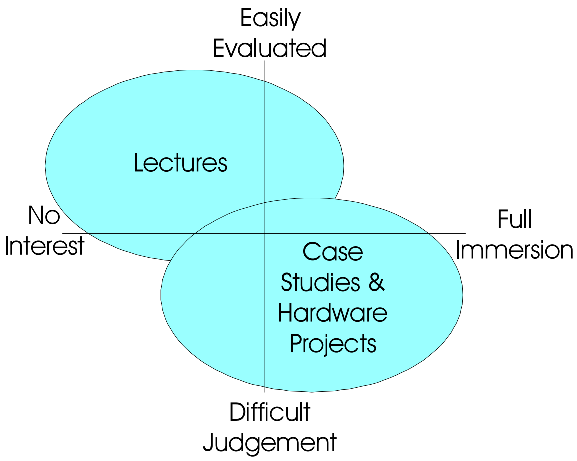

Figure 5: Perceptual Map for Consistency

Application

This paper has compared the attributes of case studies and hardware projects to traditional lectures. The author believes that traditional engineering lectures can be complimented in most engineering courses with some innovative active learning methods. A decision tree for verifying application of these active learning methods is provided in Figure 6.

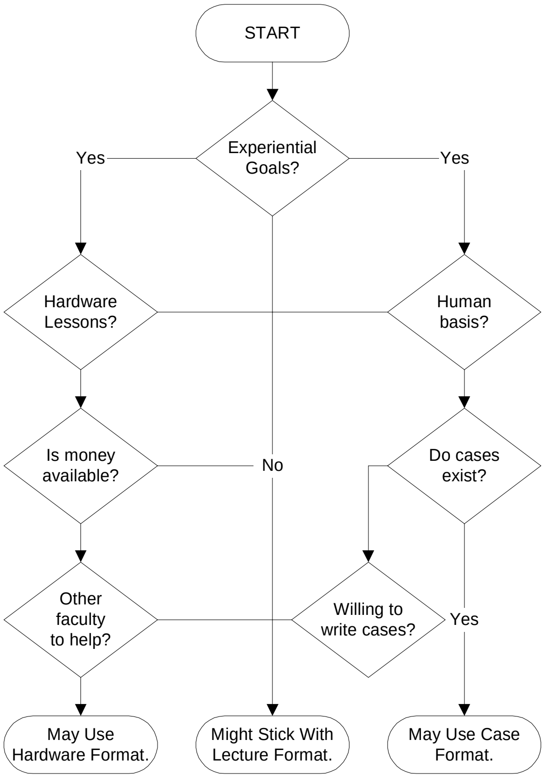

Figure 6: Decision List for Alternative Methods

Conclusions

This paper has considered the use of case studies and hardware projects as a compliment to the traditional lecture format in engineering education. Most engineering practitioners would argue that engineering students become engineers by doing engineering. Yet as educators we fail to provide sufficient experiential opportunities for students to ground their abstract engineering knowledge in physical experience and intuition. The author would like to suggest that engineering educators have not leveraged case studies or team projects as successfully as business schools. The result of our shortcomings as educators is evidenced not only by the stinted professional growth of our graduates, but also by many dissatisfied corporations who draw upon our graduates as resources [2].

The recent move to increase active learning will certainly provide engineering schools with increased opportunities to improve their curricula through significant federal dollars. These same federal dollars will be further fueled by the current need for an increased number of engineering graduates entering the technology arena. As such, the future for engineering education is extremely bright should the community choose to provide a vision and plan.

Dedication

This paper is dedicated to Dr. Philip Barkan. Phil was considered a pioneer in engineering education and the Design for Manufacture field. Phil was a caring mentor, insightful researcher, and a good friend who fundamentally changed my life in many domains and continues to inspire me.

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