EXAMINING INTERDISCIPLINARY INNOVATIONS IN ENGINEERING UNDERGRADUATE LABORATORY

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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THE WORKPLACE IS CHANGING. IS EDUCATION CHANGING WITH IT?

The growth of jobs in science, technology, engineering, and mathematics (STEM) is projected to reach 8% over the next decade, far exceeding the overall 3% growth of the job market (U.S. Bureau of Labor Statistics, 2021, p. 1). As the demand for engineering professionals grows, it is important to look for ways improve undergraduate education to best prepare future workers. Within a rapidly changing field, engineering education must not only emphasize technical mastery but also more adaptable skills such as "communication… [which] is an integral part of the intellectual design enterprise" (Hirsch et al., 2001, p. 4). It is widely acknowledged that undergraduate laboratories are "an essential part of undergraduate… programs" (Feisel & Rosa, 2005, p. 1), and that such instructional labs can "provide an optimal learning environment to prepare students as future workers" (Admiraal et al., 2019, p. 1). As the field of engineering expands and changes, how can the undergraduate laboratory be innovated to meet it?

The goal of this paper is to try to respond to the question: how can the engineering undergraduate laboratory be innovated to better prepare the student for modern work? The strategy for answering the overall question is to first understand how the current lab structure came to be. The Social Construction of Technology (SCOT) theory (Bijker et al., 1984, p. 1) will be used to examine the social forces that influence the educational structure, clarifying the priorities and strategies in the design of the prototypical engineering lab. An analysis of the shortcomings and potential areas of improvement in the current lab model will then be developed, along with a discussion of why these aspects of the lab may not be the best way to prepare students. Several case studies of attempted innovations to undergraduate engineering education will follow, such as the interdisciplinary lab structures at Northwestern University conducted by Hirsch et al. and the communication-intensive courses at the Massachusetts Institute of Technology studied by Craig et al. These components will pave the way for a conjecture at the benefits of and counterarguments against modifications to the introduction to engineering (ENGR) courses at the University of Virginia. The goal of this paper is strongly coupled to the accompanying technical work of building a brushless DC motor for educational use in the labs at the University of Virginia.

THE SOCIAL CONSTRUCTION OF THE UNDERGRADUATE ENGINEERING LAB

The undergraduate laboratory is in itself a form of technology, a technology that has been applied at many universities and continues to evolve. Viewing the lab in this way opens a new perspective on it: that lab structure is the result not only of technical challenges, but of the applications and perceptions of it by social groups. The first to propose such a view formally were Bijker, Bonig, and van Oost in their renowned paper, “The Social Construction of Technological Artefacts” (1984, p. 1). The authors posited that technological evolution is often driven by the problems that social groups apply it to, making “the perception of problems and solutions by members of those social groups” (Bijker et al., 1984, p. 3) the main focus of developmental analysis. Thus the theory of the Social Construction of Technology (SCOT) was born, with the central tenets that the perspectives of social groups drove design, and that objects could become ‘reified’ or accepted across a wide swath of social groups (Bijker et al., 1984, p. 7). Viewing the structure of the engineering laboratory through this lens will help not only to elucidate why the lab is in its current state, but also whose perceptions must be changed and how in order to effect change on the lab.

THE HISTORY AND ANALYSIS OF UNDERGRADUATE ENGINEERING LAB

Seeing the design process as an accumulation of social forces and “the alternation of variation and selection” (Bijker et al., 1984, p. 4) couples well with the excellent history of the laboratory and its varying focus compiled by the engineering professors Feisel and Rosa. According to the pair, engineering education finds its roots in apprenticeship, and became the engineering course and lab as college engineering schools proliferated in the mid-1800s (Feisel & Rosa, 2005, p. 2). The initial goal of apprenticeship was undoubtedly to train the student to copy the exact vocation of the teacher, and was therefore very practically, rather than theoretically, oriented. An emphasis on practice would have likely made the laboratory a significant part of the undergraduate education, with a focus on experimentation and practical application. Feisel and Rosa assert as much, with “institutions develop[ing] curricula that placed heavy emphasis on laboratory instruction” and by extension the “hands-on practicum… [that] can only be learned and practiced in the physical laboratory” (2005, p. 2). The first step in engineering education can be viewed neatly through a problem-solution structure created by a social group, in the spirit of SCOT: the group of current engineers needed new workers to perform known tasks, and so trained students in order to perform these specific tasks.

The prevailing focus of the undergraduate lab changed drastically, however, after World War II. Many of the greatest innovations of the war were developed by scientists rather than engineers, prompting the American Society for Engineering Education (ASEE) to commission the Grinter Report (Feisel & Rosa, 2005, p. 2). The Grinter Report proved a major shift in engineering education, recommending greater emphasis on theoretical work and a two-tiered educational system (Froyd et al., 2012, p. 2). The two-tiered system proposed, in which a more general course of study would replace several specializations, was met with opposition due to the possibility of losing military funding (Froyd et al., 2012, p. 2). However, the report did result in "engineering curricula mov[ing] from hands-on, practice-based curricula to ones that emphasized mathematical modeling and theory-based approaches" (Froyd et al., 2012, p. 2). The Grinter Report was the first major shift in engineering education, and reveals more interested social groups and artifacts which have helped shape the laboratory: public policy officials interested in keeping programs on the cutting edge, military research dollars, and the faculty who depend on those dollars to enhance their educational programs.

Engineering accreditation boards have played a role for many years in defining excellence in engineering education. The main organization for such accreditation, the Accreditation Board for Engineering and Technology (ABET), provided the second major shift in laboratory focus. After coming under criticism for its criterion, ABET developed the Engineering Criteria 2000 (EC2000), a set of accreditation criteria that focused on learning outcomes rather than specific courses or benchmarks within the engineering curriculum (Froyd et al., 2012, p. 3). Looser guidelines focused on outcomes rather than process gave institutions greater latitude to experiment and teach, while keeping an overall vision of what engineering education entails. These criteria include emphases on basic theoretical knowledge, technical skill, teamwork and the "ability to communicate effectively" (ABET, 2020, p. 1). Knowledge of the history of these social forces, in addition to emerging trends of design emphasis, the application of behavioral sciences to teaching education, and the use of computers coupled with research on the social forces of contemporary engineering education (Froyd et al., 2012, p. 1; Cheville, 2012, p. 1) provide the basis of the SCOT model for undergraduate lab shown in Figure 1.

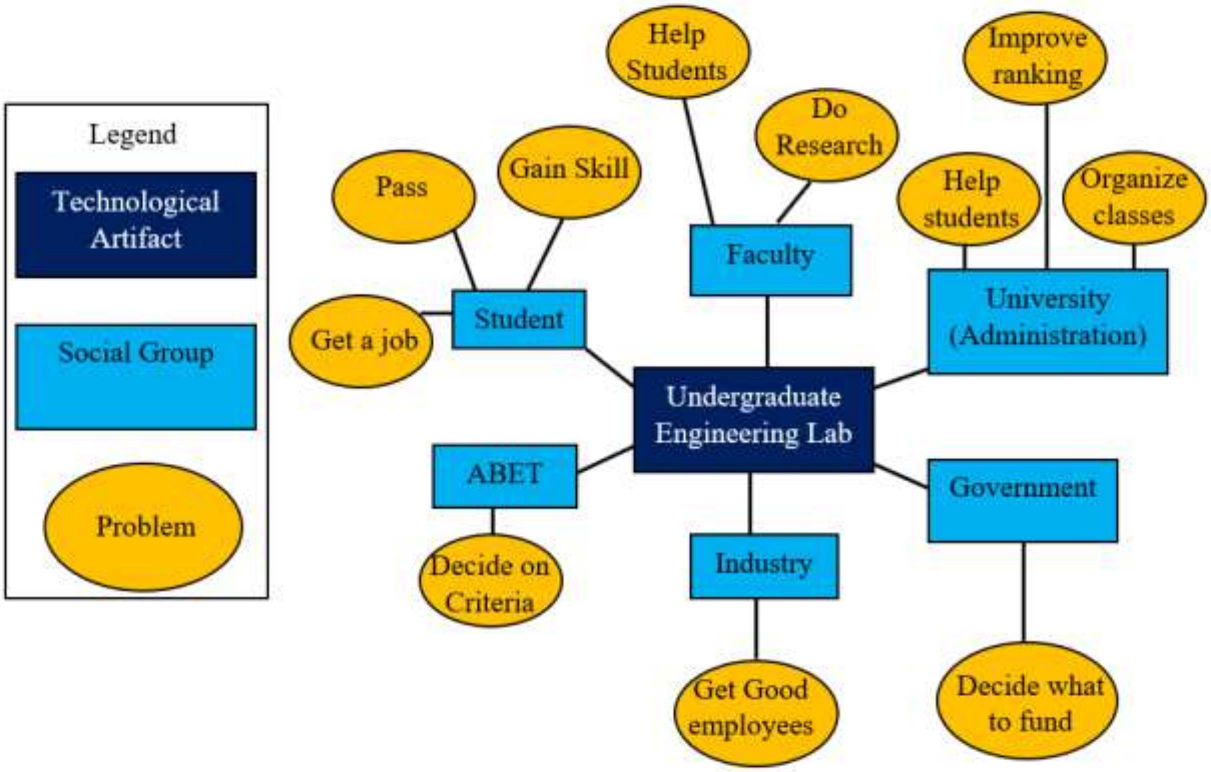

Figure 1: A SCOT Analysis of the Development of the Undergraduate Engineering Laboratory. (Adam McGill, 2021)

The SCOT graphic above reflects the tension between the philosophical focuses of theoretical and technical learning, as well as the external, practical concerns of the need for funding, the desire of the government to foster an innovative populous, the concerns of the individual student, and the demand on faculty to produce profitable research. Some of these groups have conflicting internal goals – for instance, faculty are invested in the success of their students, but the “role of research in the multifaceted careers of faculty is increasing in importance” (Cheville, 2012, p. 4), limiting the time that faculty can devote to students. The overall message of the figure is that there are many groups with different perceptions of the goals of engineering education.

THE SPACE FOR INNOVATION IN ENGINEERING LABORATORY

Returning to the goal of this paper, the motivation for producing Figure 1 (p. 5) and using SCOT analysis was to clarify the priorities and strategies in the design of the prototypical engineering lab. With this done, it is worth revisiting the central question: how can the engineering undergraduate laboratory be innovated to better prepare the student for modern work? To realize the space for innovation, it is necessary to understand where the current lab structure could be falling short. The easy question to ask is: have these forces produced a successful or unsuccessful undergraduate lab? However, this question is too vague, and it must be clarified. As the history of engineering education in the previous section has shown, there are many definitions of success criteria; success as defined by the student, success from the technical or theoretical perspective, success from the perspective of industrial support, and more. Based on the central question of this paper, success will be defined as students being able to enter the work force more quickly and effectively. There are many instances of communication or collaborative failures in the workplace. For example, shortcomings in technical documentation and requirements communication are frequent, even while the increasing complexity and global nature of work demands increasing teamwork (Aghajani et al., 2019, p. 1; Liebel et al., 2018, p. 1; Sheppard et al., 2003, p. 1). These examples suggest that the current engineering laboratory must adapt to meet the needs of a workplace environment with an emphasis on communication and collaborative skills in addition to a technically sound foundation.

Returning to the SCOT model, issues with teaching communication and collaboration can be theorized. While the needs of the workplace require interdiscplinary work, the structure of engineering labs are often siloed or specialized into majors, due in part to the organizational challenges facing administrators. While intelligent professors are selected, the ulterior motive of gaining good research faculty observed in the SCOT model could interfere with having a well-rounded engineering instructor – for instance, a great solid state device researcher may not necessarily make a good teacher of requirements elicitation and clear communication. To adapt to these issues, several experimental undergraduate course models have been proposed, often with a focus on interdisciplinary, project-based learning and collaborations between communications faculty and engineering professors. A few of these case studies are presented in the subsequent section.

COMMUNICATION-INTENSIVE TEACHING AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

In the early 2000s, a new set of curricula was adopted at the Massachusetts Institute of Technology (MIT), motivated by the belief of engineering graduates that "lack of training in writing and speaking was a significant hurdle to their professional success" (Craig et al., 2008, p. 1). The consensus at the university was that several communication-intensive (CI) engineering courses should be adopted, that answered both: "What forms of writing should students be doing…[and] What activities encourage students to work and think like professional engineers?" (Craig et al., 2008, p. 1). The courses sought to address the "skill sets that engineers must now have in communication and teamwork" through joint efforts of engineering and science faculty, often coordinated around undergraduate laboratory work (Craig et al., 2008, p. 1).

A large body of Craig et al.'s research in the paper is devoted to case studies of experiences within these modified courses. These case studies seek to illustrate examples of how the classes themselves have been honed throughout their lifespan. For instance, one of the lessons from the first case study, the experience of a student in a biomedical CI laboratory course, emphasizes the need to find “the right balance between structure and openness” (Craig et al., 2008, p. 6). While there are shortcomings in the implementation to be learned from, the authors emphasize the importance of the overall lessons they are teaching. These lessons center around gaining communication skills and research experience via “lab experiences that approach “authentic” activity,” and the importance of team skills due to their prevalence in the workplace (Craig et al., 2008, p. 7). These goals by no means eclipse the need for traditional learning; rather, they are intended to supplement strong technical and individual knowledge.

INTRODUCTION TO ENGINEERING AT NORTHWESTERN UNIVERSITY

Following work on experimental new classes such as those at MIT and Arizona State University, Penny L. Hirsch and her colleagues (2001) at the McCormick School of Engineering and Applied Sciences at Northwestern University adopted a new course format (pp. 1-2). Hirsch, whose focus at Northwestern is teaching writing and communication, banded together with other professors from communication and engineering backgrounds to create an interdisciplinary introductory engineering course (Hirsch, 2001, p. 6-7). Their goal was to demonstrate why “an interdisciplinary course… is a successful model worth emulating” (2001, p. 5) in engineering education.

The specific course used by Hirsch is the Engineering Design and Communication (EDC) course at Northwestern, which blends an introductory design course with a communications class (Hirsch et al, 2001, p. 2). The authors argue that their implementation of an interdisciplinary course improves student education by “giving… a solid foundation in design… [and] by studying design and communication in conjunction with real projects” (Hirsch et al, 2001, p. 2) in order to prepare students for practical engineering work. The course was crafted so that students from all different engineering focuses worked together on project designs for real clients, offering diverse projects and experience communicating “[not] under fictional circumstances [but] rather… to fulfill a real need” (Hirsch et al., 2001, p. 5). The Northwestern faculty stress the importance of a user-centered approach in order to motivate students and offer applicable assignments, as well as the interdisciplinary teaching to show that “thinking and communication go hand in hand” (Hirsch et al., 2001, p. 5), along with the two-semester format to give sufficient time for the class. Hirsch and her colleagues emphasize the power of real projects to motivate students and argue that teaching skills in an interdisciplinary manner improves retention by demonstrating how those skills intersect (2001, p. 5-7). Student reviews and faculty comments support the success of the course, and the EDC still survives (albeit with a modified title, Design Thinking and Communication) as a required freshman engineering course at Northwestern (Northwestern, 2021, p. 1).

APPLYING LESSONS TO THE UNIVERSITY OF VIRGINIA

Both of the cases above focused on the need for more emphasis on communication, teamwork, and interdisciplinary skills in engineering education, and are supported by many similar studies (Klaasen, 2018, p.1; Li et al., 2019, p. 1; Roppel et al., 2000, p. 1). In order to support and implement such approaches to undergraduate engineering lab education, it is possible for several of the social groups listed in Figure 1 (p. 5) to exert their influence on the design process, or frame innovations to lab structure as solving the problems of each group. An example argument for modifying the introduction to engineering courses (ENGR 1620 and ENGR 1621) at the University of Virginia (UVA) is made below.

There are multiple ways in which an interdisciplinary laboratory course with emphasis on communication and teammwork taught through projects could help solve shortcomings in preparing students for an interdisciplinary workplace in which they have to convey their ideas effectively. From the SCOT model, it is known that a common goal of both the university and its students is to increase the percentage of students hired out of college and raise the average salary of those students. This would benefit the students themselves, the reputation (and possibly ranking) of the university, and the industries which hire students out of college. Faculty members, who are busy and have additional interests in research, could help reduce their workload by teaching courses collaboratively with faculty with english or communications skills, while showcasing their own research as part of the analyses and assignments in engineering laboratory. Teaching interdisciplinary courses with communication and teammwork would meet the ABET accreditation requirements, keeping the university well-situated to maintain its accreditation.

It is possible that such a course would present organizational challenges. Therefore, the introduction to engineering courses, ENGR 1620 and ENGR 1621, present the best candidates for this new structure. Since both courses involve heterogeneous mixtures of engineering interests, they are a natural fit for interdisciplinary work, requiring less reorganization. While it is true that the university currently supports interdisciplinary projects in these courses, the course goals and implementation are largely under the control of each professor. The variance in the course caused by different teachers leads to large fluctuations in the quality and rigors of assignments that train good communication truly reflect the workplace environment. As Feisel and Rosa suggest, “clear learning objectives are essential in designing an efficient learning system” (2005, p. 3). Perhaps a more institutionally unified structure, such as that seen in the case study of Northwestern University (Hirsch et al., 2001, p. 1) would help resolve issues of inconsistency. Concerns surrounding the professor’s ability to innovate at the level of his or her own section are valid, but the success of Northwestern and MIT suggest that such a collaborative course would bring clear benefits to the quality of education.

CONCLUSION: THE ADAPTABILITY OF THE LABORATORY

The main ideas of this paper are based around answering the central question: how can the engineering undergraduate laboratory be innovated to better prepare the student for modern work? After using SCOT analysis to see which social groups contribute to shaping the engineering laboratory, it was possible to see that some restriction of focus and lack of expertise in communication education existed in the current lab structure. These issues were found to negatively affect workplace performance, and were deemed important enough to illicit innovative new lab courses at MIT and Northwestern University, among other institutions. These courses emphasized not only collaboration of students on projects, but also collaboration of faculty with both technical and communications expertise. The problems solved by such courses provided an answer to how laboratory work can be innovated to better prepare students for the workplace. An argument was made for such a course at the University of Virginia, stated in a way to show why the various social groups who have the power to shape the technology of engineering lab should see it as a positive. While struggles will doubtless remain in implementing laboratory education, it should be emphasized that the history of the engineering educational laboratory has been characterized by its changeability. Therefore, changes in the workplace should invite adaptation in lab education, the staple of the resiliency of the engineering laboratory ever since its genesis.

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