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Revolutionizing Mechanical Engineering Undergraduate Curriculum

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Dr. Plumlee is certified as a Professional Engineer in the state of Idaho. He has spent the last ten years establishing the Ceramic MEMS laboratory at Boise State University. Dr. Plumlee is involved in numerous projects developing micro-electro-mechanical devices in LTCC including an Ion Mobility Spectrometer and microfluidic/chemical micro-propulsion devices funded by NASA. Prior to arriving at Boise State University, Dr. Plumlee worked for Lockheed Martin Astronautics as a Mechanical Designer on structural airframe components for several aerospace vehicles. He developed and improved manufacturing processes for the Atlas/Centaur rocket program, managed the production implementation of the J-2 rocket program, and created the designs for structural/propulsion/electrical systems in both the Atlas/Centaur and J-2 programs. Dr. Plumlee also worked at NASA's Marshall Space Flight Center as an engineer in the Propulsion Laboratory. In practicing the engineering profession as a conduit for preparing future generations of engineers, he wants to provide students with both a technical competency and the ability to understand and respect the trust that is invested in us by society. As an educator, he guides future engineers through a learning process that develops a strong technical foundation and the ability to independently cultivate further technical competencies. He is particularly interested in advocating for project-oriented engineering education. He and a research team at Boise State University is currently participating in a project focused on encouraging the adoption of project-based techniques.

REVOLUTIONIZING MECHANICAL ENGINEERING UNDERGRADUATE CURRICULUM

Abstract

As the age of technological advancement and occupational opportunity continues to progress, companies must be constantly adjusting and transforming in order to accommodate industry demands. With these quickly developing requirements comes an expectation of employee experience and skill sets. For individuals seeking a career in mechanical engineering, moving forward with the tools necessary for success in this continuously evolving world begins with higher education. This paper is the first of a three-part series to report on the progress of Boise State University's Mechanical and Biomedical Engineering Department's mission to implement a revolutionized curriculum in their academic program. This paper will describe the establishment of goals and processes used to design a curriculum that will provide undergraduates with an effective foundation for the future. Integrating a change of this magnitude necessitated consideration of a multitude of factors. The primary motivation being to allow students to pursue more diverse and relevant fields of knowledge; this includes more flexibility within course requirements, as well as offering more availability in degree emphases. Incorporating experiential learning was also given acute attention; constructing courses with an increase in hands-on learning, creating class curriculum focused on instilling proper communication and presentation skills, and merging previously taught subjects to better assist student understanding. With these initiatives in mind, the department began formulating a reformed mechanical engineering curriculum based off review of peer institutions and educational literature. Faculty, as well as student and industrial advisory boards, aided in validating this adjusted degree program. During this development phase, several constraints had to be addressed: the curriculum must continue to be ABET accredited, align with university degree policies, appease stakeholders, and serve as an overall practical solution. With all of these factors carefully considered, faculty can begin to develop a curriculum outline to be revised and implemented into their programs. The process of developing goals and constraints for a revolutionized mechanical engineering curriculum that will serve the students of the future is described in this paper.

Introduction

In the past twenty-five years, society on an international scale has witnessed a significant shift in cultural needs and living dynamics; this fluctuation is specifically related to an extreme expansion in the fields of science and technology. The growing global market competition, the subsequent restructuring of industry, the visible transformation from defense to civilian work, the utilization of new materials and biological processes, and the explosion of information technology (both as part of the engineering process and as part of its product) has dramatically and irreversibly altered how mechanical engineers operate [1]. In the midst of these evolving times, it has become noticeably apparent that there is a considerable disconnect between what industries need from the matriculated students they hire and what undergraduate mechanical engineering education actually provides [2]. The primary issue: most university curricula have been hardly, if at all, modified throughout this revolutionized age. This worldwide transition has spiked many calls for new engineering competencies and a corresponding gradual change in both curriculum and pedagogy in mechanical engineering education [3].

Several individuals and organizations have published reports and initiatives urging for the previously mentioned reform. The National Academy of Engineering's (NAE's) Engineer of 2020 Project centered on an effort to envision the future and use that knowledge to predict the roles that engineering will play. While of interest, the exercise was also intended to provide a framework that would be used in subsequent fashion to position engineering education in the United States for what lies ahead, rather than waiting for time to pass and attempting to respond. This initiative is not unique in that other groups have similar efforts under way, such as the report established by ASME (American Society of Mechanical Engineers) [4]. ASME began their Strategy Vision 2030 project back in 2008; utilizing the perspectives of engineering managers in industry, recent mechanical engineering graduates, and education leaders, they prepared a report to offer recommendations on how mechanical engineers should be educated to meet the demands of their transforming profession as well as the grand societal challenges of the future. ASME developed six aspects of the educational landscape for the year 2030 that are target areas for change: richer practice-based experience, stronger professional skills, more flexible curricula, greater innovation and creativity, technical specialization, and new balance of faculty skills [5]. This proposal, while not the only one of its kind, does quite well at effectively summarizing the present issues surrounding collegiate level mechanical engineering education. Boise State University's (BSU's) Mechanical and Biomedical Engineering (MBE) Department recognized that their arising curriculum concerns aligned with those described by ASME's Vision 2030 and used the initiative and its suggestions as a starting point to revolutionize their own mechanical engineering program.

In August of 2017, BSU's MBE Department held an annual faculty (including administrators) retreat to kick-off the upcoming academic year. The present members reviewed the process to date in crafting a new curriculum after receiving mixed feedback from students, faculty, neighboring industry and other stakeholders. Making note of the program requirements mandated by the university and by ABET, the attendees identified key topics that were to be covered in each course. This analysis was organized by topics (thermal fluids, solid mechanics, dynamics and controls) and activity emphases (design, experimental and computational). It was then determined that research was to be conducted regarding mechanical engineering curriculum reform in order to construct a more ideal solution. This began with administrators and faculty separating tasks with the use of a three-tier system (Fig. 1).

Figure 1. *Three-Tier System Used to Design New Mechanical Engineering Curriculum at a Specific Department.*

At the top of the pyramid lies the Chair Leadership, whose responsibilities focused on overseeing the design and progress of the new mechanical engineering curriculum. The Program Operations Committee (POPs) made up the middle section; they served as the project's coordinating body. Curriculum Alignment Teams (CATs) were the foundational tier whose shared goal was to develop the curriculum specifics. As Spring of 2018 drew to a close, the teams (faculty) had developed two versions of a revolutionized curriculum that met defined criteria (provide a practical alternative, gain university and ABET approval, etc.). These involved parties met regularly over the 2018-2019 academic year to further develop the curriculum materials in preparation for a Fall 2019 submission to the University Curriculum Committee (UCC).

The implementation of this revolutionized mechanical engineering undergraduate curriculum will create an environment where students can thrive. The university will produce alumni that are better prepared and highly qualified for their leap into industry. With the ever-changing world quickening its pace, it is of the highest importance to focus on providing the next generation of mechanical engineers with the tools and proper instruction needed to be successful.

Establishing Motivation

The idea for a modernized bachelor-level program at BSU's MBE Department was developed based upon a range of stakeholder inspirations, one of the most critical being student feedback. Through course evaluations and direct reflection of learning, undergraduates had requested more flexibility with class selection, more hands-on engineering, and more themed learning tracks. The faculty recognized these inquiries to be of similar premise to those presented by numerous mechanical engineering education reform initiatives and publications. In these documents, the discussion of the disassociation between industry needs and what mechanical engineers new to their careers are prepared to provide is relentless. With the understanding that the present curriculum had not been revitalized to accommodate current workforce demands, faculty and administrators of the program commenced further research and analysis of mechanical engineering education reform with the expectation of creating a revolutionized course of study for their students. This process was officially initiated at the department's 2017 Fall faculty retreat, where attendees began with the discussion of personal principles, then professional values, and concluded with the development of a three-year strategic plan of action. Like universities before them, it was decided early on that the ASME Vision 2030 report would be specifically used as a blueprint for the new mechanical engineering degree [6] at BSU. Those devoted to the POPs Committee designed potential curriculum maps of courses and down-selected based upon full faculty consideration; the CATs then filled in the courses on the map with appropriate learning outcomes. With a loosely prepared outline of what the reinvigorated curriculum would entail, faculty members approached their department's industrial and student advisory boards to examine whether or not they would be supportive of the notion. The industrial advisory board was firm in their decision to back the initiative; they clearly stated that the workforce is in dire need of better prepared entry-level mechanical engineers. The student advisory board was enthusiastic about the idea of gaining more hands-on experience, as well as eager to see their peers have easier access to obtaining minors and emphases. Between the accessible research, student and industry support, and faculty agreement, the department made the decision to move forward in constructing a revolutionized mechanical engineering curriculum.

Literature Review

While faculty had begun the process of selecting the essential concepts from each of the previously taught courses to carry over, they also drew inspiration from the ideas presented by academic literature. Engineering education reform initiatives were of the first to be reviewed. As previously mentioned, ASME's Vision 2030 and NAE's Engineer of 2020 Project were two of the projects that served as a foundation for the renovated curriculum. The six aspects for change presented by ASME's Vision 2030 - valuable hands-on experience, focus of professional integrity, curriculum flexibility, opportunities for innovation and creativity, technical specialization, and faculty skill adjustment [5] - were used as an umbrella over further research. Another project serving as a driving force was the NSF RED Program (National Science Foundation Revolutionizing Engineering Departments Program). This initiative's goal is to catalyze revolutionary, not incrementally reformist, changes to the education of the next generation of engineers by calling upon the advice of stakeholders such as industry, the public, government, and the profession itself [7]. Combining the basis of these three presented faculty with the objective of completely revitalizing curriculum for mechanical engineering students, instead of simply incorporating minor changes over an expanded timeline.

Analysis of the research performed on the six educational aspects described in ASME's Vision 2030 was then initiated. Engineering is one of the last remaining four-year professional degrees, meaning the curricula is typically jam-packed with courses to the point where there is very little flexibility within the programs [2]. While many universities find it challenging to rebuild an entire curriculum and would prefer to implement modest changes [3], reducing, reordering, and combining all current core classes would offer greater flexibility to students [8]. This modification could create a more prominent learning environment. Donald Wroblewski studied the benefits of linking concepts in the primary mechanical engineering courses and specifically stated that "...material retention can suffer due to the lack of connectivity among various core topics" [9]. This flexibility would also more than likely result in an increase of elective hours;

students would then be encouraged to pursue a concentration of courses that could lead to a minor in another field. Students would likewise possibly obtain the motivation to acquire a focus area within mechanical engineering that would better prepare them for the career or graduate program they are interested in [6]. With the ability to pursue subjects that they are passionate about, students would be more engaged in their coursework and produce more innovative and creative solutions to engineering problems presented in the classroom.

Back in 2011, ASME designed a survey sent to industry professionals of all sizes that inquired about the strengths and weaknesses engineers possess when first entering the workforce. The study had over 1,000 respondents and concluded that "the greatest three weaknesses were lack of practical experience - how devices are made and work, oral and written communication, and problem solving/critical thinking" [10]. This explicitly demonstrates how undergraduate engineering students are not gaining valuable hands-on experience. Dr. Reuven Katz states that "the task of engineers is to create solutions and design systems to meet social, industrial, and commercial needs. Engineering education must, therefore, produce engineers who can design" [11]. Considering that design is widely regarded as the main activity in engineering, it has never been more urgent for students to gain design experience from their education. However, while every ABET accredited engineering program is required to have a capstone or similarly named project, most universities only provide such an experience in the senior year of the degree [6]. There are two primary solutions to the given issue: offer a curriculum with a rich-project base and/or promote co-curricular activities. This type of curriculum would entail, say, yearly design projects, while the extra-curricular activities would include both service-learning tasks as well as large cross-disciplinary programs such as the Baja SAE events or ASME Student Design competitions [3].

In a journal submitted by the University of Minho [12], it was expressed that there is a growing concern that mechanical engineering education is increasingly becoming out of touch with professional expectations. Since current teaching/learning methods are essentially those practiced in a world that existed a generation or two ago [1], crucial skills are not being developed in young engineers. Courses have proceeded to be labeled as too theoretical and not appropriately responding to industry needs [12]; however, without firm input from external stakeholders, the academic engineering community is not likely to institute a process-oriented approach to remake the curricula [3], [13]. In a circle that appears to be infinite, there is no denying that mechanical engineering undergraduates must be prepared to tackle the challenges they will face when entering the workforce. A collection of publications [12], [14] have determined the key professional skills an engineering student should possess include the ability to work in multidisciplinary teams, effectively communicate (both orally and written), have an innovative and entrepreneurial spirit, understand computer modeling and simulations, capable of solving problems and managing conflict, process information, and be aware of cultural, social, and economical frameworks.

From this literature review it is apparent that students, faculty, and professionals have all noticed the disconnect between what undergraduates are learning and what they are actually taking away from their university experiences. The time for change is now.

Aspirational Targets

Based upon the decided motivations and literature analysis that the new curriculum was being designed to meet, attainable goals were set forth by the faculty. The first of these being to provide students with more flexibility when selecting courses to complete their undergraduate degree. This altercation would not only be more attractive to undecided students but supply a curriculum that could easily adapt to future industry changes. Students would now have the ability to move classes around without the limitation of excessive prerequisites, as well as be able to participate in an internship without the fear of falling behind an entire academic year. Going hand in hand with schedule flexibility is the objective of creating a curriculum that offers more focused themes or emphasis areas. Minimizing the amount of core credit hours in exchange for an increase in electives would allow for students to tailor their degree; pursuing both certificates and minors would become much more accessible. This also presents an opportunity for them to seek cross-disciplinary experience, creating a more diverse and professionally desirable student in the process. This new structure would be required to expand upon experiential learning. This entails the implementation of various mechanical engineering design projects throughout the degree, as well as providing students with valuable hands-on experience. The mechanical engineers in training will have full access to and be encouraged to use resources located on BSU's campus, such as the newly created Engineering Innovation Studio. In the classroom, theory is to be applied to a broad spectrum of real-world applications. It is the idea that in order to recruit engaged students, they must be supplied with an engaged curriculum. Faculty will be granted the chance to integrate authentic problems and projects from industry versus the typical textbook questions that are often isolated from the complicated factors of real-life applications [9]. At the end of the day, this newly designed curriculum must support industry needs so that students in the program will be able to confidently venture out into their chosen careers. In order to achieve this design projects are to be presented before the senior year, guest lecturers will be encouraged, and the industrial advisory board included in making meaningful decisions.

Constraints

In order to implement a newly designed curriculum, certain restrictions must be analyzed cohesively with desired aspirational targets. One factor to consider as a constraint is appeasing the program's stakeholders. The curriculum must inspire faculty to undertake the task of developing new teaching methods and choosing relevant material, convince industrial advisory board (IAB) that supporting this adjusted program is within their best interests, and appeal to undergraduate mechanical engineering students. There is also a matter of practicality to consider as a constraint. Once the curriculum has been fully developed, it must go through the approval process set forth by the university. There are certain general requirements laid out by the institution, such as falling in between the minimum and maximum credit hours for a standard four year undergraduate bachelor's degree, acceptance by the UCC and the university financial board, and presentable justification that the curriculum is a significant improvement from the one it intends to replace. It is also necessary for the new curriculum to be accepted by the Accreditation Board for Engineering and Technology (ABET). This can be accomplished by having the institutional representative responsible for ABET-accredited programs notify the incorporation of any changes by providing detailed information about the nature of each change and its impact on the accredited program [15].

Other Considerations

Without the relentless support and drive of the Mechanical and Biomedical Engineering Department faculty and administration at Boise State University, educational revolutionization would not be fathomable. In fact, the skepticism of faculty regarding engineering education as a scholarly activity has created an environment at many institutions that make the pursuit of deeply focused and productive engineering curriculum improvements anywhere from difficult to impossible [16]. Needless to say, faculty collaboration is of utmost importance. In order to effectively examine the proposition of a new curriculum, the mechanical engineering faculty at BSU reminded themselves of their department professional values before each meeting: to be innovative, impactful, inclusive/respectful, cooperative/collaborative, and professional/ethical. The cultivation of these shared values ultimately served as the initiators of the revolutionized curriculum and carried on solidifying the departmental culture. This developed culture was centered around the previously mentioned principles, as well as a common vision. The shared end-ambitions were used to maintain faculty focus throughout the duration of the design process; such as to provide a specific direction, make decisions, and settle disputes. While faculty are sometimes protective in regard to their courses and can be initially resistant to enforcing changes [2], abiding by the core values they share as a singular unit helped to establish the dire need for practical discussion and alignment. Those taking leadership roles in this grand task end up devoting a significant portion of their time and energy for extended periods to implement the engineering academic reforms as needed [13].

Revolutionized Curriculum Outline

While this three-part paper series intends to use the second installment to describe the revitalized curriculum in detail, a generalized summary of changes is to be made mention of in this document. The primary high-level modification was dividing the undergraduate mechanical engineering program outline into topics and activity emphases. Topics included the threads thermal and fluids, solid mechanics, and dynamics and controls. Within these three subjects, faculty made the decision to eliminate unrelated courses and instead implement levels of understanding. For example, thermal and fluids requirements dropped from 12 to 6 credits by replacing Thermodynamics, Fluid Mechanics, Heat Transfer, and Thermal Fluids & Systems Design with Thermal/Fluids I and Thermal/Fluids II. This change came to be after professors of the thermal and fluids thread worked together to determine the important learning outcomes of each of the individual courses; these objectives were then combined into the two classes listed above. The intention behind this drastic adjustment was to provide students with more elective opportunity and learn the combined material at beginner, intermediate, and advanced levels of understanding. Activity emphases included the threads design, experimental, and computational. The primary revision within these three subjects was to create more hands-on experiences for students in the form of design classes spread out over the entirety of the four-year program.

Discussion and Conclusion

The twenty-first century has borne witness to profound technological and societal advancements, some taking the world by storm overnight. While companies have done their best to adjust to their ever-transforming surroundings, undergraduate level mechanical engineering education has fallen behind. In simplest terms, colleges are producing students underprepared for future challenges. In order to bridge this divide, industry and education must serve as one another's primary stakeholders, and work closely together in expressing their individual needs. With ASME's Vision 2030 functioning as the base premise, Boise State University's Mechanical and Biomedical Engineering Department began the process of devising a revolutionized mechanical engineering curriculum for their students. With motivations, research, and constraints carefully considered, this department strongly believes that they are on the right track to providing mechanical engineering students with the skills and experiences needed to be successful and valuable in their future careers.

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