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An Exploration of the Use of Technical Electives in Engineering Curricula

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Abstract

A standard feature of many, if not most, undergraduate engineering programs is the requirement that students in the program take a certain number of technical elective courses. The widespread and long-standing use of this requirement in engineering programs may have led to a situation where many faculty do not even consider the purposes these courses serve, or whether requiring students to take a certain number of these courses is in the best interest of the students. The intention of this paper is to start a conversation on the purpose and appropriate number of technical electives required in an undergraduate engineering program.

Technical electives can provide students with a number of benefits. One benefit is that technical electives give students the opportunity to learn specialized knowledge of an advanced nature that they can then apply to their work in various subfields of engineering. For example, a mechanical engineering student interested in the electricity-generation industry would benefit from taking technical elective courses in traditional power generation methods and in renewable energy technologies. But by their very nature as electives, technical elective courses should not be teaching material that is expected to be learned by every student graduating from a particular engineering discipline. Requiring students to take several such courses may impact their ability to take courses from other disciplines which may be beneficial to them in achieving their personal career goals. Therefore, it is important for engineering programs to consider the results they are intending to achieve by requiring students to take technical electives, how these courses may be impacting the overall education of the students, and what is an appropriate number of technical elective courses to require. It can be noted that ABET accreditation requirements should not be forcing programs to require students to take technical elective courses.

In this paper, an overview of the nature of technical elective courses will be provided. The potential benefits and detriments of requiring technical elective courses will be explored. The paper concludes with some recommendations of what engineering programs should do as they consider the optimal number of technical elective courses to require of their students.

Introduction

Engineering programs in the United States are often seen as having a very rigorous and a very rigid curriculum. Students entering these programs should expect that they will be embarking on a challenging course of study that will prepare them well for a career in engineering. Students also will find that the rigid curriculum employed by most programs offers little opportunity for students to explore other interests that they may have in other disciplines.

An engineering curriculum can generally be divided into three main components. Students need to master basic science courses and mathematical material at and above Calculus. Students need to take general education courses to satisfy a university's graduation requirements and to provide students with an education in non-STEM disciplines; while not always the case, many of these courses are of a fairly low-level, designed to be taken by 1st and 2nd year students with little

background in the discipline. Most programs then use the remainder of their available credits for engineering courses. This can lead to a requirement of students taking 60 or more credits in engineering courses. Most of these courses are specific required courses, which provide the fundamentals of the discipline to the students. Some of the credits are usually allotted to technical elective courses, which generally contain material that is deemed of interest to some students in the discipline, but that is not necessary for all students graduating from the program to learn. The use of technical electives provides some options for students to tailor their studies to their particular interests in engineering.

Historically, most programs have required students to take several technical elective courses to graduate. But as a historical presence in a curriculum, many programs have not given much recent consideration to the appropriateness of this requirement. While there has been much discussion of other aspects of engineering education, including the incorporation into the curriculum of more "soft-skills", class delivery modes, and capstone design project requirements, there has not been much discussion of the appropriate role for technical electives. This is somewhat surprising considering the desire of many programs and universities to reduce the number of credits required for an engineering degree in an effort to increase graduation rates, reduce time-to-graduation, and decrease student debt loads. With this in mind, the primary purpose of this paper is to prompt discussion of the purpose of technical electives, and the appropriate number of technical electives that a program requires.

To initiate this conversation, this paper will provide an overview of the general types of technical electives offered in engineering programs and the formats used by programs to offer the electives. The paper then considers the benefits and detriments that technical electives can provide. Following this, there is a set of recommendations that programs, and the engineering education community in general, can use as a starting point for deeper discussions on the role of technical electives.

Types of Technical Elective Courses

Material that must be covered for students studying an engineering discipline should be covered in required courses. The reason for this is that when students are given options as to what courses to select, some will end up not choosing a particular course, and if necessary material is covered in that course the student will not learn that material. A possible way around that problem is discussed later, but we will primarily consider truly elective courses to contain material that is of use and interest to some students in a discipline, but not material that is necessary for all students to learn.

Most engineering technical elective courses can be categorized as either a general course of an advanced nature or as a course on a specific, rather narrowly-focused, topic. We will refer to these categories as "general courses" and "specific courses". An example in Mechanical Engineering of a general course is a second-semester course in Thermodynamics that would cover a variety of topics that are more advanced than in a basic Thermodynamics course, but not deemed by the program as topics necessary for all graduates to learn. For example, such a course might cover power cycle analysis, psychrometrics, and combustion – topics that are important to some mechanical engineering graduates, but would be unused by many in their

careers. An example of a specific course is a course on HVAC system design. Such a course would cover some of the material taught in the described general elective course on Thermodynamics, but would delve more deeply into the duplicated topics, and then move into specific concepts and tools used in HVAC system design.

Looking at these two types of elective courses, a general course may provide students with knowledge that would be of use in many areas and lay the groundwork for future in-depth studies, but lacks the details that a student would need to be fully prepared to enter into a specific industry. A specific course may give a student the knowledge and skills to enter a specific industry at the risk of providing relatively little knowledge useful outside that field.

Beyond these two broad categories, there are some courses that may be considered more experimental in nature, where an instructor or team of instructors may use the category of a technical elective to offer a course that is interdisciplinary in nature and moves beyond the traditional engineering course. Additionally, some programs will use the category of technical electives to house such courses as a co-op experience, study-abroad, or independent study. This is appropriate, but it should be noted that there is often a limit as to how many credits students can take from such coursework in their program. These specialized courses are outside the scope of this paper, with the primary focus being on the appropriate use of general and specific electives courses.

Technical Elective Course Offering Formats

A program can offer its technical elective courses in several different formats, some of which are discussed here. A common format is to have a set of stand-alone advanced courses in an engineering discipline. In this format, students choose from an array of courses that focus on a particular topic, including both general courses and specific courses. In this offering format, students may choose to take courses that are related to each other, or may take a variety of technical elective courses that are of interest to a student without a particular focus other than the broad engineering discipline which offers or accepts the courses as technical electives.

A second offering format is directed towards having the students earn a concentration in their discipline, either as a requirement of graduation or as an option available to students. In this format, technical elective courses are grouped together by a general subdiscipline. Students choose from the courses available in the subdiscipline and take the necessary number of courses to earn the concentration. As an example from Mechanical Engineering, there may be concentrations available in mechanical design, thermo-fluids, controls, etc. A program might choose to require students to choose their electives to satisfy a concentration, so that students can be considered specialists in a subdiscipline of that field of engineering. Alternatively, a program may only make the earning of a concentration optional, to allow students more flexibility in designing their program of study.

A third way to offer technical electives is to cover a specific skill or piece of knowledge that is considered necessary for students in a discipline to learn in a few technical elective courses, and then require students to take one of those particular courses. In this offering format, a program is still able to teach the material that is deemed necessary for students to learn before they graduate,

but allows students to apply that knowledge in particular applications that are of the most interest to them. For example, suppose that a program wishes to teach students how to design laboratory experiments. The program could teach this in one particular laboratory course. Or the program could offer two or three laboratory courses that focus on different particular subdisciplines in the field, and teach students in each of these courses how to design experiments. By requiring that students take at least one of these elective courses, the program guarantees that the students are taught the important topic of designing experiments. But this approach gives the students flexibility in learning about a particular subdiscipline in greater detail through the elective courses while learning the necessary topic. While this approach may not be widely used in engineering programs, it does provide the students with some programmatic flexibility while assuring that necessary topics are covered despite being taught in elective courses.

Potential Benefits of Technical Electives

Before considering specific potential benefits and drawbacks of technical electives (and in particular – requiring students to take a certain number of credits from technical elective courses), it should be stated that if a student chooses to take a technical elective course that is of great interest to that student, and if the course is well-taught, the scenario really only presents benefits to the student. So most of what will be discussed with regards to benefits and detriments are not related to this ideal scenario.

There are a number of benefits that students can potentially gain by taking technical electives. First, technical electives can provide students with detailed knowledge of topics that can be of great use to students entering into a specific industry. For example, a student wishing to work for a solar energy company would likely benefit from the knowledge that could be gained by taking a technical elective course in solar energy. It is unlikely that most of this knowledge would be covered in required courses in most engineering programs.

Similarly, but not as specifically, technical electives allow students to tailor their technical education to specialize in a subdiscipline of their broader major. An advantage of specializing in a subdiscipline is the opportunity for the students to build a depth of knowledge in an area that students taking a more general approach to an engineering discipline may not gain. Additionally, students can take courses that might not be directly related, but that would provide them with a set of skills that they feel will give them an edge in their planned career. This approach might not lead to a recognized concentration, but the student could describe their work in elective courses to potential employers as they seek a job.

Technical electives provide students with the opportunity to apply their engineering knowledge to advanced and specialized problems beyond the scope of those in most required courses. Additionally, technical elective courses can give students practice in combining subject matter from different required courses to solve engineering problems. Students should be receiving these types of experiences as part of their undergraduate curriculum, but technical electives provide an additional venue for students to practice their skills.

Programs and faculty often use technical electives to recruit students to graduate school, or to encourage graduate school attendance. The reasoning behind this approach is that by exposing

students to more specific and/or more advanced material, some of the students will wish to pursue even deeper studies on these topics by attending graduate school.

When considering the benefits described above, a program should consider whether or not it is beneficial to the students in the program to be required to take a certain number of electives, or whether the benefits should be simply made available to interested students by offering technical electives. The answer to this question can vary by program, based on the philosophy a program takes with regards to what it seeks to achieve with its graduates.

An additional benefit to some programs depends on the budget model used by an institution. If an institution distributes at least a portion of the budget based on the number of student credit hours taught by a program, then requiring students to take a certain number of technical elective courses from the program may produce greater income to the program. This would not be the case if a program were simply replacing a required course with a requirement that the student take an elective course. But if a program were to require students to take elective courses from inside their program rather than from other programs across the institution, this would bring in more revenue to the department. The program could then use that additional revenue to enhance its offerings to the students.

Potential Detriments of Technical Electives

While there are clearly some benefits to students in taking technical electives, requiring a certain number of technical elective courses to be taken can be disadvantageous for some students.

One potential drawback of requiring students to take a large number of technical electives is that the students may be forced to take a course that is of little interest to them. Consider a situation where you have an engineering discipline with a few broad subdisciplines. Now, consider that the program offering this discipline has a small number of full-time faculty members, and has budgetary constraints restricting the program's ability to hire adjunct instructors to supplement the faculty. As a result, the program has enough instructional capacity to offer the required courses in the program, but is only able to offer one or two technical electives each semester. This means that in any particular semester or year, there will be no technical electives offered in at least one subdiscipline. Students with a particular interest in that neglected subdiscipline will not be able to take technical elective courses that interest them, and will have to take technical elective courses that may be of little or no interest to them to graduate. While some students might learn that they are interested in another subdiscipline, many students will enter these courses with low motivation for learning.

Taking this idea of a program with staffing issues a step further, a situation can develop where a program continually offers the same technical electives each year, with only rare variations to the offerings. If the number of these offered technical electives equals the number of technical electives the program requires the students to take, you have a situation where the students don't have any options in terms of what to take. While still called elective courses, the students would not have options as to what they take, making them de facto required courses. If these courses are teaching material not deemed critical for graduating students to have learned from the program, and if the courses are in subjects of little interest to the students, the students are being

forced to take additional courses that they may see no purpose in taking and that do not help them in their career goals.

The idea of not supporting a specific student's career goals can be seen in another potential detriment to requiring technical electives be taken. To consider this issue, a review of ABET Criterion 5 on the curricular requirements established by ABET for accreditation is helpful [1]. Currently, ABET requires an engineering program to have 30 credits of math and basic science, 45 credits of engineering topics, and a sufficient number of credits to meet a university's general education requirement. This last number will vary, but as an illustration consider it to be 21 credits. This means that for a program which requires 120 credits for graduation, there are 24 credits which the program can use at its discretion. In reality, most programs will use more than 45 credits in engineering topics; in many cases, the program believes that more knowledge is required for engineers entering a discipline than can be covered in 45 credits. But it needs to be acknowledged that ABET and the various professional organizations that contribute to ABET believe that 45 credits of engineering topics are what a student needs to take to receive a degree in engineering and begin their profession as an engineer.

When an engineering program fills its curriculum with requirements that students take 60 or more credits of engineering topics (which is common), the program is limiting what the student can do in terms of following different career trajectories. (There are many examples of programs that require over 60 credits on engineering topics; the references include only a few examples from a variety of disciplines and institutions [2], [3], [4], [5].) With so many engineering topics credits mandated beyond what ABET requires, a program may need to consider if it is trying to provide more knowledge than necessary for an entry-level engineer. Consider that ABET also expects engineering graduates to have the ability to acquire new knowledge throughout their careers (Criterion 3 – Student Outcome 7) [1]. It is recognized that engineers will need to continue to learn after they graduate, and so programs with very high requirements for credits in engineering topics should consider if they are trying to teach much more material than is necessary for the students to learn by the time they graduate.

There are many students who are very focused on their engineering studies and who want to take more engineering courses because it is their main interest and will help prepare them for their planned career. Requiring such students to take technical electives is not an issue, as these are courses that the students want to take. But many students do not fit into this category. Starting in 2021, the Mechanical Engineering Department at the University of Wisconsin-Milwaukee has allowed students to take free electives rather than technical electives offered by the program [6]. As the results in Table 1 show, this led to a very large decrease in the number of students registering for the technical electives offered by the department. Instead, students generally (but not exclusively) were choosing to take simpler courses from other disciplines to reduce their time to graduation. The context of the data in Table 1 is that Fall 2019 was a pre-COVID semester, and is representative of the previous several years of the program, Fall 2020 was conducted primarily on-line, and saw a general decrease in the number of students taking courses in the program, and then both Fall 2021 and Fall 2022 were semesters with primarily in-person course offerings with small decreases in student enrollment – but with students no longer being required to take a certain number of technical electives to graduate.

Table 1: Technical elective course offerings and student enrollment in the technical elective courses offered by the Mechanical Engineering program at the University of Wisconsin-Milwaukee for the Fall semesters from 2019 to 2022. The "enrolled students" counts students enrolled in more than one elective course multiple times.

Semester	Enrolled Students in Technical Elective Courses	Number of Technical Elective Courses
Fall 2019	204	10
Fall 2020	160	7
Fall 2021	18	5
Fall 2022	10	5

While potentially an extreme case, the results in Table 1 indicate that there are many engineering students with interests beyond engineering. This suggests that there likely is a group of students who may be interested in a plan of study that would result in an "engineering and ___" education, where the student might either double-major in an engineering and a non-engineering discipline, or major in engineering and minor in another non-engineering discipline. This could be a plan stemming simply from educational interest, or because the student believes that such an educational background could help them reach their particular career goals. For example, a student may wish to major in an engineering discipline and minor in a world language because they would like to work in a country that uses that language specifically.

When an engineering program requires students to take technical electives such that the requirements add to the number of engineering credits giving a total that far exceeds ABET requirements, a program ends up giving students very little flexibility in their program of study. Students interested in an "engineering and ____" education would need to choose between taking a substantial number of additional courses to graduate with the multiple credentials and just focusing on engineering and foregoing the additional studies. This does not benefit such students. Additionally, there are students who have an interest in engineering and in other topics, and choose to not study engineering due to the lack of flexibility offered in many programs. These students, and their talents, are lost to the engineering community. Therefore, requiring a large number of technical elective credits may be a disservice to students looking at different career paths, and could dissuade students from entering in or staying in engineering studies.

The typical engineering technical elective course focuses on engineering topics from an engineering perspective. However, there are benefits to exposing engineering students to non-engineering perspectives [7], [8]. These benefits include the engineering students gaining a better understanding of the problems faced by people in real-world situations, and learning ways to better communicate technical subject matter to people lacking deep technological literacy. Additionally, ABET Criterion 3 – Student Outcomes for accreditation emphasizes the need to take into account global and societal factors in creating engineering designs and making engineering judgements [1]. To achieve this student outcome, students must have a good understanding of global and societal factors, and that understanding may be gained more easily through more interactions with a wide variety of other students, rather than taking more courses

with engineering students. Depending on the type of technical elective courses being offered and the number of other electives available in the curriculum, requiring a large number of technical elective courses may be detrimental to engineering students by reducing their potential exposure to seeing problems through a non-engineering lens. However, it should be noted that through innovative course design, technical electives that include non-engineering students or interactions with non-engineers could turn this potential detriment into a good opportunity for students.

Recommendations

Echoing previous work [6], the first recommendation to be made is that programs look in depth at the required courses in their curriculum, and carefully consider what is being taught. Do the courses contain material necessary for graduates in the program to perform well in their chosen discipline? Is there extraneous material that might be of use to some students but that is not something that will be of much use to most of the students? Such an investigation may not lead to the direct elimination of a course, but may lead to the consolidation of courses, or the opening of space in existing courses to move some of the skills covered in the technical elective courses into required courses. By doing this before addressing the issue of requiring a certain number of technical elective courses, a program can have a good idea of what type of flexibility is available in their curriculum while meeting a target number of credits required for graduation.

The second recommendation is that programs have a discussion as to the appropriate number of technical elective courses to require, and the method the program will use to offer these courses. This discussion should be informed by a broader discussion throughout the engineering education community on the purpose and best use of technical electives in an undergraduate program.

To start the conversation, after consideration of the benefits and detriments of technical electives, below are some broad recommendations for programs to consider.

1) If electives are being used as described by the third offering format described above (the requirement that students take one of a few specific elective courses, with the same fundamental being taught in each of those courses), programs should strive to have all expected skills and knowledge be covered in required courses. While it is appropriate to strengthen a skill or knowledge in a technical elective, truly elective courses should not be used as the sole point of presenting a required skill or piece of knowledge.

2) If not already done, consider offering specific recognized concentrations that can be earned through taking a particular set of technical electives. This provides interested students with a tangible demonstration of accomplishment.

3) Do not require that a certain number of credits be earned through technical electives, unless the program needs to do so to meet ABET curricular requirements. This does not mean that a program shouldn't offer technical electives; it does mean that programs should not compel students to take courses that (a) are unnecessary for their basic education, and (b) may limit their ability to structure their program of study to best suit

their overall interests and career goals. If this recommendation is followed, it is important that it be coupled with comprehensive advising of the students. Along those lines, it is recommended that the technical electives not be replaced by completely free electives, but rather there be an expectation that students are taking some advanced courses from whatever discipline they choose. This could be achieved by asking students to propose how they plan to fill their elective course credits, and have those plans approved by the program before the courses are taken. This type of approach has been used by some programs [9], [10].

4) If a program decides it wishes to require students to take some technical electives, it is recommended that this number be kept small – perhaps requiring only one or two technical electives. This approach would allow for many of the benefits of technical electives to be achieved while not overly burdening students who may wish to pursue studies in non-engineering areas as well.

5) Consider incorporating interdisciplinary work and non-engineering perspectives into the offered technical elective courses.

While decisions on the program's structure shouldn't be driven by the desires of the students, programs can benefit by consulting with current students and recent graduates to learn more about their career goals and interests. The data in Table 1 were considered in the context of there being students who have interests other than engineering. But it can also be noted that the results in Table 1 indicate that there are likely many engineering students who do not wish to take additional engineering courses if they do not need to. How students view their education is not universal. If a program receives input from current students on their career goals, their overall interests, and their views on the amount of coverage devoted to different topics in the program, a program may be able to better choose the number of required technical elective courses and meet the needs of the students as they study to become engineers.

Summary

There is no single answer to the question surrounding the appropriate use of technical elective courses in undergraduate curriculum. The answer will vary depending on factors such as the overall structure of the curriculum, the program's educational objectives, the type of student the program attracts, and the types of courses considered to be technical electives by a program. Therefore, it is necessary that individual programs have discussions on both the general nature of their curriculum and how technical electives appropriately fit into the program of study. Such discussions may result in engineering graduates who are better prepared for their professional work. These discussions could also lead to the development of programs that draw in more students to engineering studies by allowing for them to seamlessly study both engineering and other disciplines. In particular, programs that have not carefully considered the nature and use of technical electives in their curriculum in decades should do such an analysis of the appropriate number of required technical electives for their students.

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